QC
983
.A27

MONTHLY WEATHER REVIEW

VOLUME 80 NUMBER 8

AUGUST 1952

CONTENTS

Page

Interpolation of Missing Precipitation Records
J. L. H. Paulhus and M. A. Kohler 129

The Weather and Circulation of August 1952 . . . . . Harry Hawkins, Jr. 134

Hurricane Able, 1952 . . . . . R. B. Ross 138

Charts I–XV (Charts IV and V, Snowfall, omitted until November)

U. S. DEPARTMENT OF COMMERCE · WEATHER BUREAU

UNIVERSITY OF MICHIGAN
GENERAL LIBRARY

QC
983
A27

CORRECTIONS

MONTHLY WEATHER REVIEW, vol. 80, No. 6, June 1952, p. 95: line 2 of abstract should read " . . . synoptic weather reporting *stations* does not permit . . . " p. 97: abscissa of figure 2 should be labeled "Percentage of Rain *Days* in the Area".

MONTHLY WEATHER REVIEW, vol. 66, No. 9, Sept. 1938, p. 281: equation should read

$$\cos h = \frac{\sin a - \sin \phi \sin \delta}{\cos \phi \cos \delta}$$

DEPARTMENT OF COMMERCE
CHARLES SAWYER, Secretary

WEATHER BUREAU
F. W. REICHELDERFER, Chief

MONTHLY WEATHER REVIEW

Editor, JAMES E. CASKEY, JR.

Volume 80
Number 8

AUGUST 1952

Closed October 15, 1952
Issued November 15, 1952

INTERPOLATION OF MISSING PRECIPITATION RECORDS

J. L. H. PAULHUS AND M. A. KOHLER
Hydrologic Services Division, U. S. Weather Bureau, Washington, D. C.

[Manuscript received August 7, 1952]

ABSTRACT

Since 1948, when the Weather Bureau discontinued the practice of publishing interpolated precipitation data, monthly and annual totals have been omitted from its publications whenever any portion of the record was missing. In view of objections by the users of precipitation data, this policy was reviewed for possible revision. A series of tests involving some 1200 storms was conducted to determine if missing records could be satisfactorily estimated by simple procedures which could be applied in the limited time available. Results of these investigations are presented and two methods of interpolation, namely, the normal-ratio and 3-station-average, are selected for use by the Weather Bureau. Procedures to be followed in applying these methods are outlined.

Because of the early deadlines for the issuance of monthly Climatological Data, estimated data, properly identified, will appear in the annual number only, beginning with the 1952 issue. In order to limit the magnitude of the errors of interpolation, annual totals including more than one-third estimated precipitation will not be published.

INTRODUCTION

In 1948, the Weather Bureau adopted machine methods in the preparation of climatological data for publication, centralizing the activities in seven (now three) Weather Records Processing Centers. One of the most important reasons for the change was to effect earlier publication of monthly data. Incident to this change, the interpolation of precipitation records was discontinued. It was not fully realized at the time what a large amount of summarized data would be thus eliminated from the publications nor how much of a demand there was for interpolation of monthly and annual totals. A survey of the 1950 annual Climatological Data for Colorado revealed that about 25 percent of the stations listed did not have annual amounts published. Moreover, totals for those months with incomplete records were also omitted. An analysis of daily records for 59 of the stations for which totals were not published showed the breakdown given in table 1.

TABLE 1.—*Frequency distribution of length of missing records*

Number of days with no record	1-5	6-10	11-15	16-20	21-25	26-30	31-55
Number of stations	21	14	10	4	4	2	4

On many days for which there was no record, observations at nearby stations showed that there was apparently no precipitation in the area. Table 2 shows the probable number of days with precipitation during periods of no record for which estimates would be required to obtain annual totals. On three occasions, the annual amounts were not published although there probably was no precipitation to be estimated, and the majority of the stations probably had 5 or fewer days of precipitation missing during the year.

TABLE 2.—*Frequency distribution of length of missing records with apparent no-rain days eliminated*

Number of days requiring estimates	0	1-5	6-10	11-15	16-20	21-25
Number of stations	3	33	14	5	3	1

The omission of annual and some monthly totals for 25 percent of the available stations is a serious handicap to many users of precipitation data, especially in mountainous areas where precipitation varies greatly from station to station and the network is relatively sparse. Continued requests that the Weather Bureau resume publication of estimated data prompted reconsideration of existing

222426—52

policy, and an investigation of practicable interpolation methods was initiated. Because of the relatively large number of interpolations that must be made and the desirability of prompt publication, the investigation of interpolation methods was restricted to simple procedures that could be used by clerical personnel or easily adapted to solutions by machine methods. For these reasons such methods as Horton's [1] inclined plane method of interpolation were not tested.

The purpose of this paper is to present the results of the investigation, and to outline procedures followed by the Weather Bureau in applying the two methods of interpolation for use beginning with July 1952 data.

REGRESSION EQUATION

A least-squares regression equation of the type

$$P_X = b_1 P_1 + b_2 P_2 + b_3 P_3 \tag{1}$$

is known to be satisfactory for estimating the precipitation (P_X) at Station X from the precipitation (P_1, P_2, and P_3) at three index stations (1, 2, and 3). However, the least-squares regression is applicable only when reports are available from all the selected index stations and, moreover, the required analysis is quite time consuming. On first thought, these disadvantages appear to make equation (1) undesirable for Weather Bureau purposes, that is, for large scale application.

Obviously, the disadvantages of equation (1) would be eliminated if the regression constants b_1, b_2, and b_3 could be obtained by some simple procedure instead of by the relatively cumbersome least-squares method. It was believed that this might be accomplished (fig. 1) by expressing b as a function of effective area (as indicated by

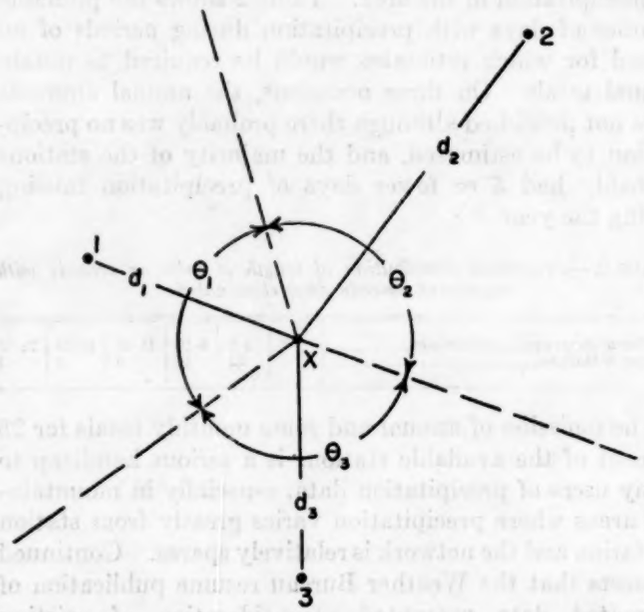


FIGURE 1.—Angle θ is formed by rays from Station X bisecting the angles between lines from X to Stations 1, 2, and 3, respectively. The relative distance between X and an index station is $d_n/\Sigma d$.

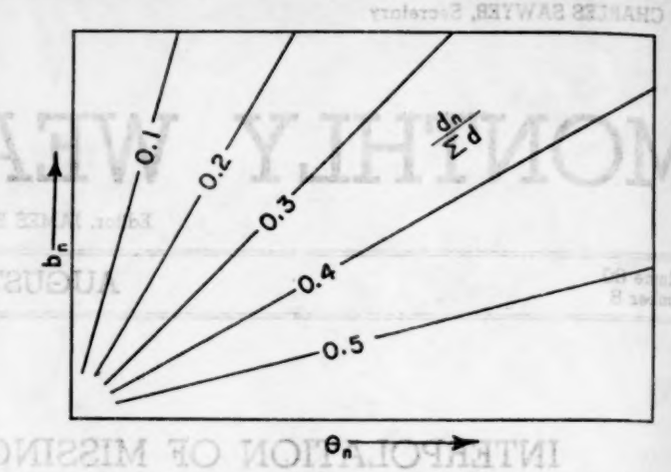


FIGURE 2.—Possible relation of regression coefficient (b_n) to effective area (θ_n) and relative distance $d_n/\Sigma d$.

the intercepted angle θ between rays from Station X bisecting the angles between lines from X to index stations 1, 2, and 3) and relative distance ($d_n/\Sigma d$) between X and 1, 2, and 3, respectively, or

$$b_n = f\left(\theta_n, \frac{d_n}{\Sigma d}\right). \tag{2}$$

By first finding the values of b_n in equation (1) for a number of different situations by the least-squares method, it would then be possible to develop a relation between b_n and θ_n and $d_n/\Sigma d$ such as

$$b_n = k_1 \frac{d_n}{\Sigma d} + k_2 \theta_n + k_3 \frac{d_n}{\Sigma d}\,\theta_n \tag{3}$$

which is shown graphically in figure 2. From this graph, it would then be possible to determine quickly the proper "b" values for any combination of stations and then use equation (1) for estimating the missing rainfall.

In testing the feasibility of this hypothesis, equation (1) was solved for 20 sets of four stations, with 60 rainy periods for each set, making a total of 1,200 rainy periods. In order to make the test as rigid as possible, all rainy periods were selected in the May-September season, when the areal distribution of precipitation is relatively "spotty". The lengths of the rainy periods used varied from 2 to 12 days.

Unfortunately, it was not possible to determine a satisfactory relation between the 60 values of b_n, obtained as in the preceding paragraph, and the corresponding values of θ_n and $d_n/\Sigma d$. The method, however, appears to merit further study.

THREE-STATION-AVERAGE METHOD

A test of equation (1) with all values of b equal to ⅓ was made next. The equation thus used is nothing more than an expression of an estimate based on the average precipitation at three stations, or

$$P_X = \frac{1}{3}(P_1 + P_2 + P_3) \tag{4}$$

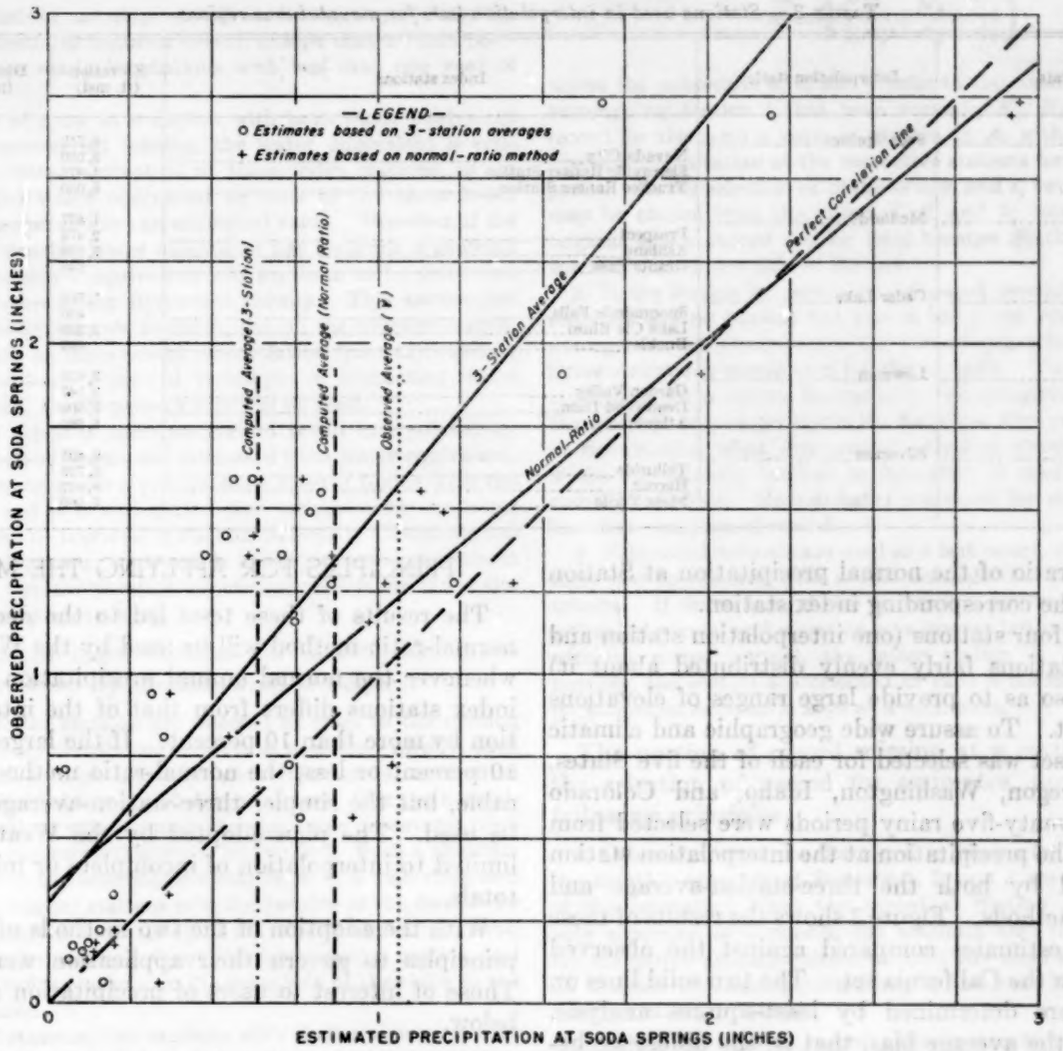


FIGURE 3.—Comparison of results of 3-station-average and normal-ratio interpolation methods in estimating precipitation for Soda Springs, Calif.

Ten sets of four stations were used in the test. Care was exercised to effect a fairly even distribution of the index stations around the interpolation station, a satisfactory distribution being considered achieved if the three index stations were located in alternate 60-degree sectors of a circle centered at the interpolation station. The estimates obtained by this method were considered to be satisfactory, though less accurate than those of equation (1) determined by the least-squares method. Horton, also, had found the three-station-average to be reasonably satisfactory.

Using the same central stations of the 10 sets used in testing equation (4), another 10 sets having four surrounding stations instead of three were selected to test whether a four-station-average would yield appreciably better results than equation (4). The resulting improvement obtained was considered insufficient to justify the added effort.

NORMAL-RATIO METHOD

Up to this point all tests had been restricted to precipitation in the Plains region. Realizing that a straight average of precipitation at surrounding stations would not always yield satisfactory estimates in mountainous regions, it was decided to test the ratio of the normal annual precipittaion (N_X) at the interpolation station to that at the respective index stations as a weighting factor, or

$$P_X=\frac{1}{3}\left[\left(\frac{N_X}{N_1}\right)P_1+\left(\frac{N_X}{N_2}\right)P_2+\left(\frac{N_X}{N_3}\right)P_3\right], \qquad (5)$$

Obviously, equation (5) yields results similar to those that would be obtained by interpolation from a map of storm precipitation expressed in terms of percentage of the mean annual. It is also obvious that equation (5) is another form of equation (1), with each b value being equal to

TABLE 3.—*Stations used in interpolation tests for mountainous regions*

Set No.	State	Interpolation station	Index stations	Elevation (ft. msl)	Distance (mi.)	Normal annual precipitation (in.)
1	California	Soda Springs		6,752		46.11
			Nevada City	2,600	35	52.17
			Sierraville Ranger Station	4,975	20	23.60
			Truckee Ranger Station	6,000	12	27.38
2	Oregon	Medford		1,457		20.26
			Prospect	2,473	30	38.99
			Ashland	2,050	14	19.98
			Grants Pass	940	24	29.75
3	Washington	Cedar Lake		1,560		103.30
			Snoqualmie Falls	430	9	55.19
			Lake Cle Elum	2,200	32	34.56
			Buckley	685	22	46.34
4	Idaho	Lowman		3,870		22.96
			Garden Valley	3,147	21	22.14
			Deadwood Dam	5,300	17	32.87
			Atlanta	5,560	30	24.51
5	Colorado	Silverton		9,401		25.37
			Telluride	8,756	12	23.87
			Hermit	8,912	31	17.35
			Mesa Verde	6,960	62	19.22

one-third the ratio of the normal precipitation at Station X to that at the corresponding index station.

Five sets of four stations (one interpolation station and three index stations fairly evenly distributed about it) were selected so as to provide large ranges of elevations within each set. To assure wide geographic and climatic coverage, one set was selected for each of the five States, California, Oregon, Washington, Idaho, and Colorado (table 3). Twenty-five rainy periods were selected from each set, and the precipitation at the interpolation station was estimated by both the three-station-average and normal-ratio methods. Figure 3 shows the results of these two types of estimates compared against the observed precipitation in the California set. The two solid lines on this figure were determined by least-squares analysis. Table 4 gives the average bias, that is, the difference between average computed and average observed precipitation, for the five sets. The normal-ratio method yielded better results than did the three-station-average method for all five sets. In four of the sets, the average error of estimate of the normal-ratio method was less than one-half that of the three-station-average.

TABLE 4.—*Average bias of estimates by 3-station-average and normal-ratio methods*

Set No.	Average precipitation observed (in.)	Average bias			
		3-station-average		Normal-ratio	
		Inches	Percent	Inches	Percent
1	1.06	−0.42	40	−0.20	19
2	.65	+.13	20	−.10	15
3	1.62	−.95	59	−.18	11
4	.42	−.04	10	+.01	2
5	.67	−.13	19	0	0

Other tests were made with ratios of normal monthly precipitation substituted for the ratios of normal annual in equation (5) but the results were not appreciably different.

PRINCIPLES FOR APPLYING THE METHODS

The results of these tests led to the decision that the normal-ratio method will be used by the Weather Bureau whenever the normal annual precipitation at any of the index stations differs from that of the interpolation station by more than 10 percent. If the largest difference is 10 percent or less, the normal-ratio method is still applicable, but the simpler three-station-average method may be used. The plan adopted by the Weather Bureau is limited to interpolation of incomplete or missing monthly totals.

With the adoption of the two methods of interpolation, principles to govern their application were established. Those of interest to users of precipitation data are listed below.

1. Interpolated precipitation amounts are not published in current monthly Climatological Data, but monthly and annual amounts containing estimated precipitation appear in the annual section summaries, and are identified by the letter "E", indicating that the amounts are wholly or partially estimated. All interpolations are made from the published Climatological Data.

2. If the total of all estimates during one calendar year is over one-third of the established annual total or the gap in record exceeds six months, the annual total and all monthly totals containing more than one-third estimated precipitation are not to be published. Whenever the annual total is published, all monthly totals are also published, even when completely estimated. In determining what percentage of a record is estimated, only that portion of the record actually missing is considered. It should be emphasized that all restrictions apply to amounts and not to number of days for which estimates were made.

3. As far as possible, interpolations are based on comparison of adjacent records covering whole storm periods that produce general precipitation. Individual daily amounts are not estimated unless the time period of the general disturbance that produced precipitation is less than 48 hours. No effort is made to interpolate daily amounts when conditions have produced sporadic or scattered rainfall.

4. Monthly totals may be interpolated regardless of the nature of the precipitation-producing processes that characterized the month.

5. Partial records of monthly rainfall are brought up to monthly totals by the procedures outlined herein, except that no interpolations whatever are made for stations with less than one year of record.

6. In the case of snow at a station with both water equivalent and snowfall measurement missing, the water equivalent is estimated from the water equivalent at three index stations, as for rain, provided the water equivalent at each of the three index stations is a measured and not an estimated value. However, if the station with the missing water equivalent has recorded a snowfall measurement, the water equivalent will continue to be estimated as in the past by assuming 10-percent density. This assumption is known to be badly in error at times, but on the average it gives results as accurate as the average interpolation from surrounding stations, and, until an improved technique of estimating water equivalent is found, the 10-percent rule will be used.

7. Snowfall or depth of snow on ground is not interpolated by the methods described herein nor estimated from water equivalent.

8. Interpolation of missing precipitation records begins with the July 1952 data, and it is anticipated that estimates for the latter portion of 1952 can be included in the annual issue of Climatological Data for 1952. However, whenever it can be undertaken without undue hardship, the interpolation of missing records for the entire year of 1952 is being encouraged.

The selection of index stations for making the interpolations is governed by the following principles:

1. The three index stations are selected as close to the missing station and as evenly distributed about it as possible. Ideally, each station should fall into an alternate sector of a circle centered at the station and divided into six 60-degree sectors. For the normal-ratio method, stations with normals showing large departures from that of the interpolation station are to be avoided. Such a situation might prevail when the interpolation station is on a high ridge and one or more of the index stations is to the lee side of the range. In such a case it is preferable to disregard the criterion governing even distribution of index stations about the interpolation station and to select instead index stations on the same side of the ridge as the interpolation station.

2. For coastal stations, two stations with similar exposures may be used, one on either side of the missing station. If the normal or average annual precipitation at either of the two stations differs by more than 10 percent from the normal or average annual precipitation at the missing station the normal-ratio method is used. For two stations this is expressed as

$$PX=\frac{1}{2}\left[\left(\frac{N_X}{N_1}\right)P_1+\left(\frac{N_X}{N_2}\right)P_2\right]$$

where N_X is the annual normal at the missing stations, N_1 and N_2 are the annual normals at the two nearby stations, and P_1 and P_2 are the respective totals for the two stations.

If a station entering into the interpolation procedure has too short a record to establish a normal, an estimate of the normal is obtained according to the following principles:

1. If one of the index stations 1, 2, or 3 has no established normal but has at least 10 years of record, the average for the period of record may be used in lieu of the normal. Normals will not be estimated for stations with less than 3 years of record. The normal for a station having only 3 to 9 years of record is estimated by extrapolation based on at least three surrounding stations. Thus, the estimate of the normal, N_1, at index Station 1 with a record of n years where $3 \leq n \leq 9$, is expressed by the formula

$$\overrightarrow{N_1}=\frac{A_1}{3}\left[\frac{N_a}{A_a}+\frac{N_b}{A_b}+\frac{N_c}{A_c}\right]$$

where the subscripts a, b, and c refer to the nearest three stations surrounding Station 1 that have normals, N_a, N_b, and N_c, and a record for the same n years as Station 1; A, with subscript, is the average precipitation at the respective stations for the same n-year period. In the selection of Stations a, b, and c, two of them usually may be chosen from the group X, 2, and 3; however, the entire original group should not be used because Stations X, B and C would all be on one side of Station 1.

2. If the station for which an estimated precipitation amount is required has no normal but has at least one year of record, the average annual precipitation for the corresponding period at the index stations is substituted for the normals. Thus, if an estimate is required for a station having only two complete years of record, the average annual precipitation for those two years only is used in determining what interpolation method should be used, and, if the normal-ratio method is indicated, is used in deriving the weighting factors. No estimates are made for stations that have less than one year of record.

3. Estimated normals are used as a last resort, that is, only when there are no stations with actual normals that meet the location criteria. If there is a choice between a nearby station with an estimated normal and a station at a greater but reasonable distance with an actual normal, the latter station is used. Wherever possible, the sectors are oriented in such a manner that the need for estimated normals is kept at a minimum.

The portion of record missing at a station determines the selection of period for estimates, according to the following principles:

1. When the record for Station X is missing for an entire month, the monthly amounts at Stations 1, 2, and 3 are used as the basis of the estimate. When the record at Station X is missing for only a portion of a month, the amounts used for estimating are for the period actually missed or for a few days longer, depending on whether the missing period begins and ends between storms or during a storm or storms.

2. When the missing record extends into two months, first an estimate is made of the missing amount for the total storm, without regard to month. Next, an estimate of the portion of the missing record in one of the two months is made using only precipitation for the corresponding days at stations having the same observation time as the missing station. Finally, the portion for the other month is obtained by subtracting the two values obtained in the preceding steps.

ACKNOWLEDGMENTS

Among the several members of the Weather Bureau's Hydrologic Services Division who took part in this study, L. L. Weiss and A. L. Shands deserve special mention—the former, for several tests that he either made personally or supervised, and the latter, for critically reviewing the manuscript.

REFERENCE

1. R. E. Horton, "Rational Study of Rainfall Data Makes Possible Better Estimates of Water Yield," *Engineering News-Record*, Vol. 79, July-December 1917, p. 212.

THE WEATHER AND CIRCULATION OF AUGUST 1952 [1]

HARRY F. HAWKINS, JR.
Extended Forecast Section, U. S. Weather Bureau, Washington, D. C.

WEATHER HIGHLIGHTS

The protracted hot dry spell of July [1], which had centered about Tennessee and affected most of the southeastern States as well as part of New England, was ended decisively in early August. Relief came as a series of cold fronts (with their attendant upper level troughs), penetrated the southern and eastern United States, accompanied by frontal overrunning and extensive shower activity which spread over most of the parched area. In many sections the relief was timely and beneficial, but some crops—early corn and Burley tobacco—were locally beyond help. A number of States were designated "Disaster Areas", thus making individuals eligible for loans guaranteed by the Federal Government, but the aggregate need for such aid was greatly reduced, as the drought was broken.

At the same time, however, severe drought conditions were becoming established in Texas. Only last May this State was reported as being nearly free of drought in all sections for the first time in two years [2]. During succeeding months conditions locally worsened and finally reached a searing climax in August. In many respects this month, for many Texas localities, was even more extreme than the hot dry August of 1951 [3]. Table 1

TABLE 1.—*Temperature and precipitation data for selected stations in Texas, August 1952*

	Abilene	Austin	Dallas	Fort Worth	Laredo	Waco	Wichita Falls
Number of consecutive days with maximum temperature 100° F. or over	*29	7	*25	25	25	*23	18
Total number of days with maximum temperature 100° F. or over	*29	20	*26	*27	27	24	27
Average mean temperature	*90.1	87.1	90.3	*91.1	89.7	88.8	*91.1
Departure of mean temperature from normal	+9.8	+3.3	+6.8	+8.4	+2.8	+3.4	+5.2
Total monthly precipitation	.02	0	.27	.44	0	T	.24
Percent of normal precipitation	1	0	10	17	0	0	11

*Record for any month.

gives some idea of the highly anomalous temperature regime and the marked moisture deficiency of August 1952. From the number of all time records broken it was not surprising that as the month closed Texas sought classification as a "Disaster Area", in order to become eligible for the government benefits which had already been made available to the eastern drought areas.

Another noteworthy feature of this month's weather was the first tropical storm of the season, which was initially reported north of Puerto Rico on August 27. This storm moved northwestward to a point about 150 miles east of Jacksonville, Fla., on the 29th. Full recurvature apparently was prohibited by a strong Bermuda High extending west-northwestward over the Middle Atlantic States. Subsequently the storm struggled north-northwestward and struck the coast south of Charleston, S. C. The center proved small but contained winds up to 75 m. p. h. as it started to move northward up the Atlantic coastal plain. As August ended, strong winds, torrential rains, and squalls (including a small tornado at Franconia, Va.) were affecting a wide area.[2]

THE BROAD SCALE CIRCULATION PATTERN

The monthly mean circulation pattern (fig. 1) shows the major North American trough at 700 mb. just east of Hudson Bay. At higher latitudes (north of 50° N.) this trough was part of a well-defined wave system of large amplitude and long wave length. At lower latitudes in the United States, there were a number of ill-defined troughs. The important features of the circulation in the United States were the penetration of the westerlies to the Gulf of Mexico, the relatively straight westerly flow over most of the country, and the narrow ridge extending west-northwestward from the Gulf of Mexico across Texas to the Southwest. Other significant features in more remote areas are also shown in figure 1.

The monthly mean 200-mb. map for August (fig. 2) presents much the same features as figure 1 but with greater simplicity and some changes in emphasis. For instance, the troughs in both the eastern Atlantic and eastern Pacific were more prominent circulation features at 200 than at 700 mb. Also, the weak (probably foehn) trough over eastern Colorado at 700 mb. was missing at higher elevations; but, the westerlies at 200 mb. extended no farther southward toward the Gulf of Mexico than they did at 700 mb. As noted in July [1], the western Pacific High seemed to be displaced far westward with increasing elevation, while the eastern lobe showed little or no displacement with elevation.

Apart from the sinusoidal aspects of figure 2, one notes the strong almost zonal west wind band which presumably

[1] See Charts I-XV following p. 143 for analyzed climatological data for the month.

[2] See adjoining article by R. B. Ross for further details about this hurricane.

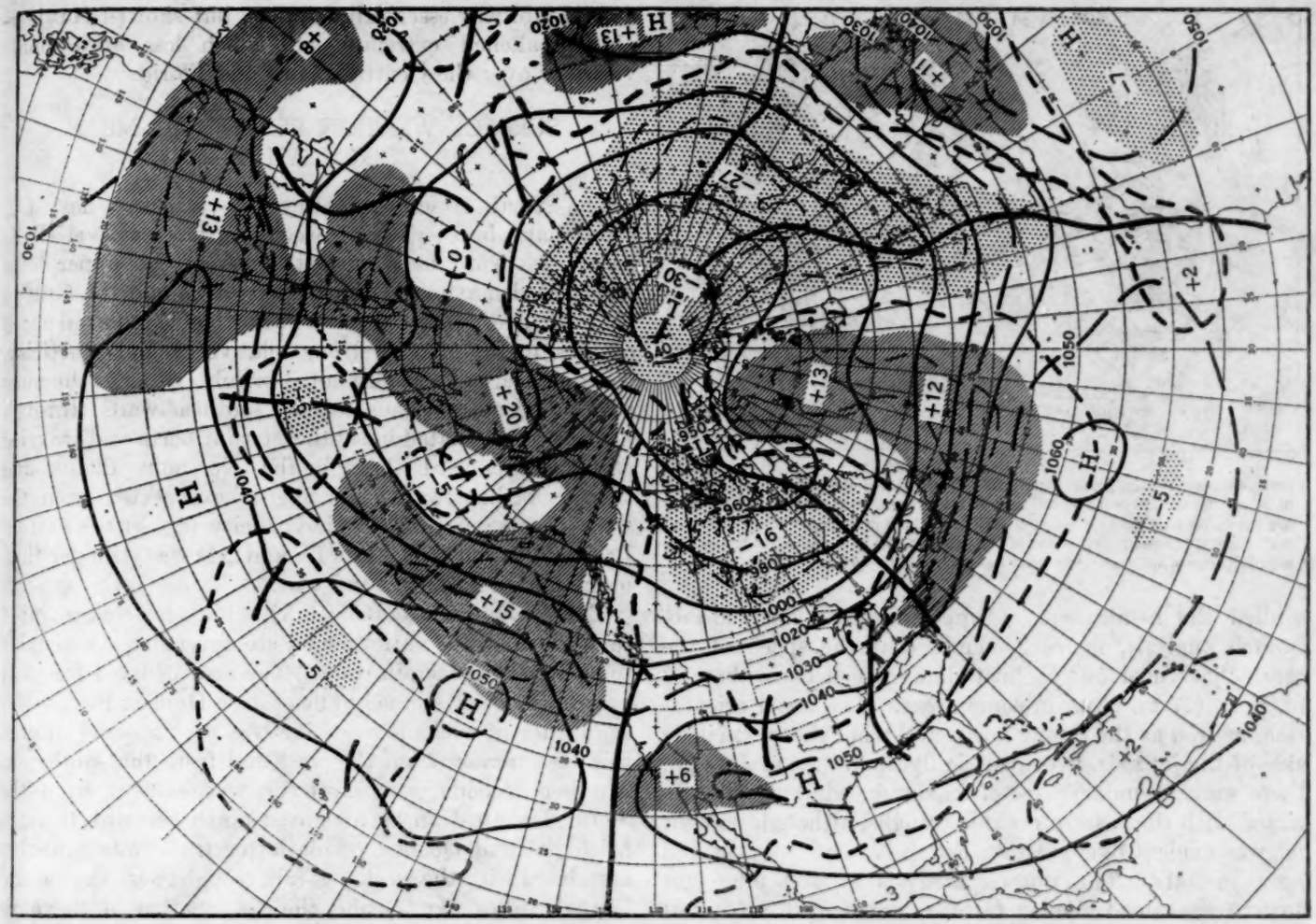


FIGURE 1.—Mean 700-mb. chart for the 30-day period August 2–31, 1952. Contours at 200-foot intervals are shown by solid lines, intermediate contours by lines with long dashes, and 200-mb. height departures from normal at 100-foot intervals by lines with short dashes with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines. Areas with 700-mb. height anomalies in excess of +50 feet are hatched; areas with anomalies less than −50 feet are stippled.

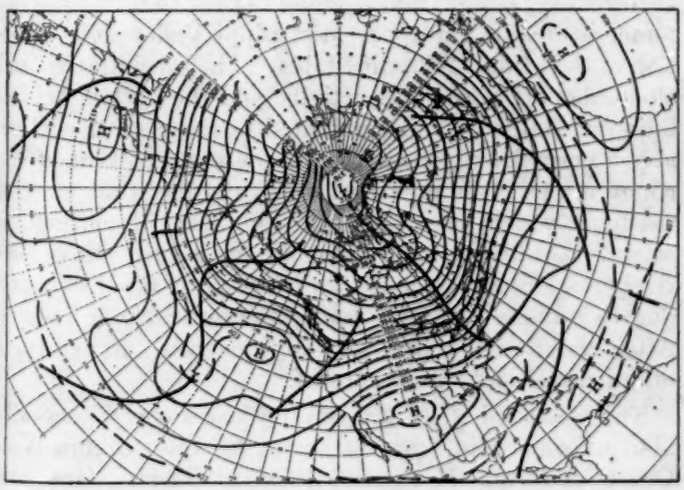


FIGURE 2.—Mean 200-mb. chart for the 30-day period August 2–31, 1952. Contours at 200-foot intervals are shown by solid lines, intermediate contours by dashed lines and minimum latitude trough locations by heavy solid lines. Contours are labeled in hundreds of feet.

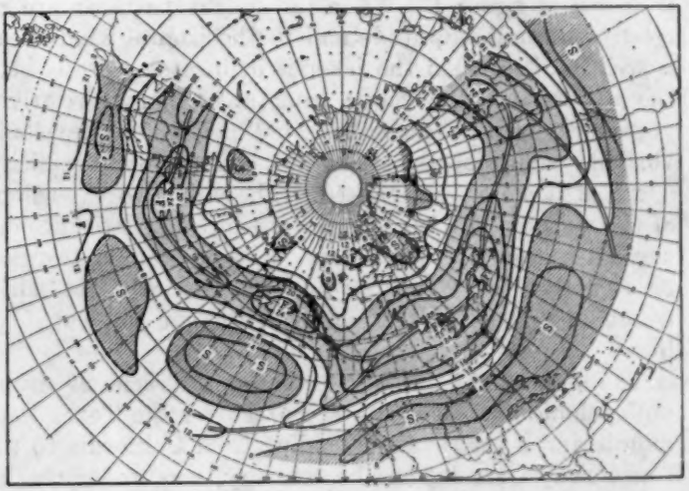


FIGURE 3.—Mean geostrophic (total horizontal) wind speed at 200 mb. for the 30-day period August 2–31, 1952. Solid lines are isotachs at intervals of 4 m/sec. Arrowed lines delineate the axes of maximum wind speed or "jets." Centers of maximum and minimum wind speeds are denoted by "F" and "S" respectively. Areas with speeds in excess of 16 m/sec. are stippled; areas with speeds less than 8 m/sec. are hatched.

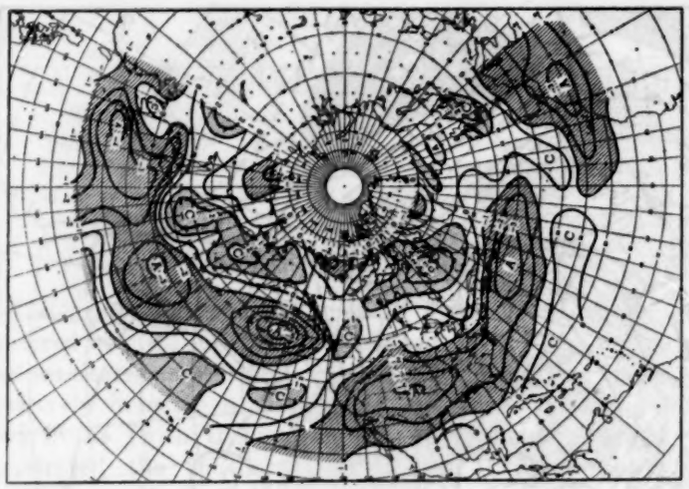


FIGURE 4.—Mean relative geostrophic vorticity (horizontal component about the vertical) at 200 mb. for the 30-day period August 2–31, 1952. Isopleths at intervals of 1×10^{-5}sec^{-1} are shown by solid lines. Centers of anticyclonic and cyclonic vorticity are labeled "A" and "C" respectively. Areas of cyclonic vorticity in excess of 1×10^{-5}sec^{-1} are stippled; areas of anticyclonic vorticity less than -1×10^{-5}sec^{-1} are hatched.

girdled the hemisphere at upper levels. The 200-mb. isotach analysis, figure 3, shows that the speed of the mean "jet" near 50° N. latitude averaged more than 60 m. p. h. (27 m. p. s.) in some areas. The zonal orientation, as well as the strong horizontal wind shear on either side of the jet axis, is evident in figure 3. As in July [1], there were secondary axes of maximum wind speed associated with the eastern oceanic troughs, although no split jet was evident over western Europe in August as it had been in July. The isotach analysis at 700 mb. (not shown) contained similar features north of 45° N., but the lower latitudes differed considerably, in the sense that could be anticipated by comparing figures 1 and 2. Both the maximum wind speeds and the horizontal wind shear at 700 mb. appeared to be less than half that at 200 mb.

Analysis of the relative vorticity at the 200-mb. level, is shown in figure 4. When the height patterns are of relatively small amplitude and the horizontal wind shear is well marked, then the jet axis delineates quite closely the separation of cyclonic from anticyclonic (relative) vorticity. In this case the zonal belts of anticyclonic vorticity south of the mean jet and cyclonic vorticity north of it were well marked. The only two extensions of the cyclonic vorticity southward into low latitudes occurred in connection with the eastern oceanic troughs. At extremely low latitudes cyclonic vorticity was fairly common in the easterlies south of the sub-tropical ridge line.

The area of the United States was the scene of strong anticyclonic vorticity with a center over the Texas Panhandle and a zonal axis extending from California to the Carolinas. Canada, on the contrary, was under the influence of cyclonic vorticity north of the jet with the maximum centered just east of Hudson Bay in the mean trough (figs. 1 and 2). The analysis of relative vorticity at 700 mb. was essentially similar, but showed considerably weakened extremes and much less anticyclonic vorticity over the Central Plains and Florida.

SURFACE WEATHER RELATED TO MEAN CIRCULATION

The North American anticyclone tracks (Chart IX) show that, almost without exception, the sea level Highs passed eastward near or just south of the upper level wind speed maxima in the Upper Lakes and the Gulf of St. Lawrence. Their occurrence north of these wind speed centers, in the area of strong relative cyclonic vorticity, was quite rare as was also noted in July [1]. For the most part the anticyclones came southeastward through Alberta or originated in southeastern Alberta and traveled east-southeastward through the Northern Plains and thence northeastward. As might be expected from the strong center of anticyclonic vorticity (fig. 4) the eastern Pacific anticyclone (Charts IX and XI) was stronger than normal and relatively persistent.

The cyclone tracks (Chart X), while less concentrated than those for the anticyclones, are nevertheless amenable to reasonable generalization. The area of most frequent cyclonic activity seemed to be eastern Hudson Bay, under the center of cyclonic vorticity (fig. 4). Storms entered this area mainly from the west and from the southwest. Another secondary storm track was evident from the South Dakota-Kansas area east-northeastward through Michigan and Quebec. This latter track was probably associated with the weak 700-mb. troughs over the central United States (fig. 1) and the deformation of the anticyclonic vorticity field (fig. 4) in this same area.

The net effect of these circulation features was to produce a generally warm temperature regime in the United States (Chart I, A, and B). Successive penetrations of the United States by cold fronts accompanied frequent anticyclone passages and resulted in near to below normal temperatures in the upper Mississippi Valley and a portion of the Middle Atlantic States. The precipitation and cloudiness attending this activity and the cyclonic circulation at 700 mb. also contributed to the near or slightly above normal temperatures over the eastern third of the country. Of some importance was the fact that most of the highs which traversed this region were of continental origin. During summer this usually implies only relatively mild invasions of cool air followed by rapid warming due to intense insolation under the anticyclonic regime. After the extreme heat of July, August temperatures afforded real and welcome relief.

The western half of the country experienced generally above normal temperatures except for the extreme West Coast and the Northern Rockies. There were two centers of positive temperature anomaly: southeastern Nevada, which had temperatures averaging 6° F. above normal, and northern Texas, where the monthly normals

were exceeded by 8° F. The cool regime of the West Coast was attributable to a combination of sea breeze and occasional intrusions of cool Pacific air due to intensifications of the West Coast trough. The warm center in Nevada was a reflection of the persistent anticyclonic regime with above normal heights aloft. Absence of showers and their attendant cloudiness (Chart VI) were also concomitant with ridge conditions in this area. Relatively cooler conditions prevailed over eastern Arizona, western New Mexico, and north-northeastward through the Rocky Mountains. In this area a weak 700-mb. trough was associated with shower activity in the western moist tongue. Cloudiness (Chart VI–B) accompanying this activity effectively reduced mean temperatures in the Rocky Mountain States. At both 700 and 200 mb. Texas was the seat of a strong anticyclone and the center of strong anticyclonic relative vorticity. The persistence of these conditions was outstanding; the resulting anomalies were considered separately in the first section of this article.

Precipitation was near to above normal over a large area (Charts II and III) which covered the Northern and Central Plains, the Middle and Upper Mississippi Valley, the Ohio Valley, and most of the Atlantic Coast States and Alabama. The breaking of the drought in the East can be readily associated with the mean 700-mb. trough in the Mississippi Valley and the strong southward displacement of the subtropical ridge into the Gulf of Mexico. In the area of generally cyclonic circulation, moisture of Gulf and Atlantic origin was released in fairly copious amounts. Cold front penetrations and a few abortive wave formations provided the mechanisms for the rainfall. In North Central United States weak trough activity in the area of below normal heights at 700 mb. was associated with the local cyclogenesis previously described. These perturbations released considerable amounts of moisture which had reached the area either from the far Southwest or by a more direct trajectory from the Gulf of Mexico.

The Southern Plains, Texas, and the Lower Mississippi Valley were dry as they remained under anticyclonic circulation aloft or, occasionally, were subjected to dry foehn winds as the westerlies penetrated farther south. The Far West also experienced below normal precipitation under the upper level ridge, except for the extreme West Coast where the mean trough was responsible for some above normal precipitation. The shower activity of Arizona and New Mexico averaged somewhat less than normal as might be expected from the westward extension of a 700-mb. ridge over this area. Nevertheless, the cloudiness (Chart VI–B) was apparently persistent enough to affect the temperatures as previously indicated.

After the devastating weather of July, August was an excellent agricultural month over much of the country. Far more crop recovery was made in the eastern States than had ever been deemed likely. The major corn belt of the Midwest was experiencing one of its best growing seasons with a bumper harvest in sight. Prospects were that 95 percent of the crop would mature before the normal occurrence of the first frost. In the South and the extreme Northeast crop prospects were well below normal but much improved. Only in Mississippi did the July drought continue during August, but the rapid development of critical drought conditions in Texas became a new source of concern.

REFERENCES

1. W. H. Klein, "The Weather and Circulation of July 1952, A Month with Drought," *Monthly Weather Review*, vol. 80, No. 7, July 1952, pp. 118–122.
2. H. F. Hawkins, Jr., "The Weather and Circulation of May 1952, Including a Study of Some Recent Periodicities," *Monthly Weather Review*, vol. 80, No. 5, May 1952, pp. 82–87.
3. V. J. Oliver, "The Weather and Circulation of August 1951," *Monthly Weather Review*, vol. 79, No. 8, Aug. 1951, pp. 160–162.

HURRICANE ABLE, 1952

R. B. ROSS

WBAN Analysis Center, U. S. Weather Bureau, Washington, D. C

INTRODUCTION

The Miami Weather Bureau Office issued its first advisory for storm Able on August 25, 1952. Navy aerial reconnaissance had reported squally conditions with a poorly defined center located at 20° N. latitude and 59° W. longitude (about 420 miles east-northeast of San Juan, Puerto Rico). The storm, moving toward the west-northwest, developed hurricane force winds in squalls on August 27. Movement continued in this direction until the storm reached a point east-southeast of Jacksonville, Fla., August 30. Then as recurvature took place, the storm became a fully developed hurricane. It then moved toward the north and crossed the South Carolina coastline August 31. After moving inland this storm maintained its identity as a closed circulation as it continued up through the Atlantic Seaboard States into Maine where it finally dissipated. Hurricane tracks dating back to the beginning of the 19th century indicate that the path taken by this storm (fig. 1) was unusual. Tropical storm tracks, as reproduced by Tannehill [1], show one storm, in August 1893, with a track almost identical to the path taken by storm Able and only two other tracks with some similarity. Storm Able took a toll of two lives and left considerable damage in its wake as a result of heavy precipitation and high winds.

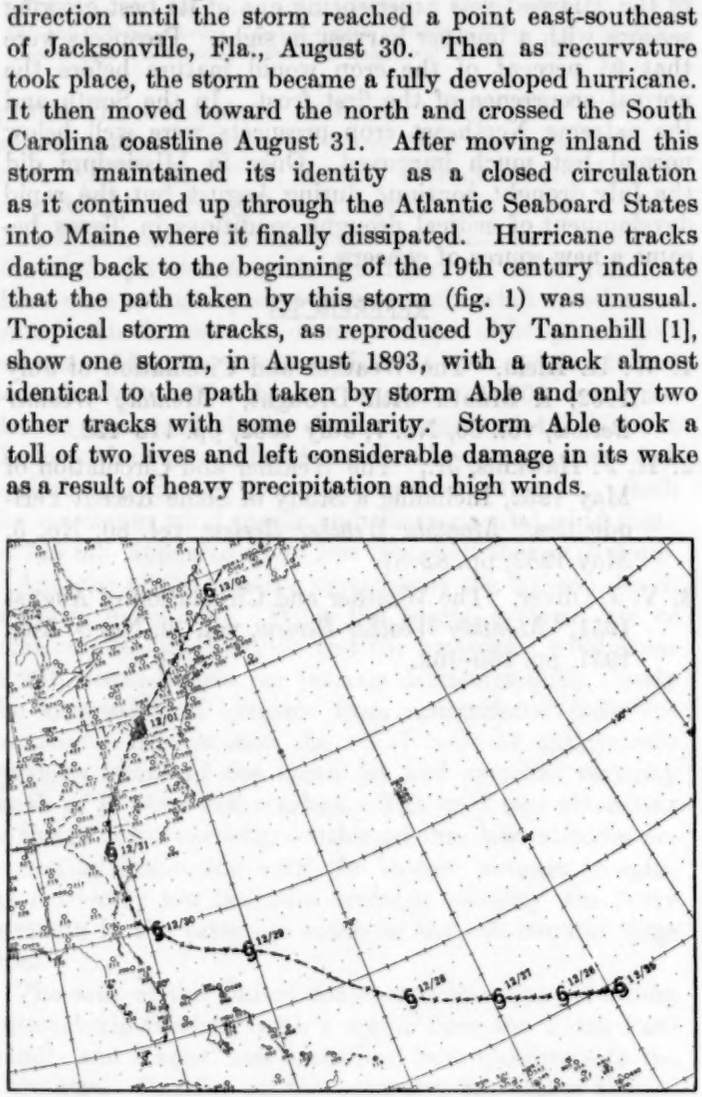


FIGURE 1.—Track of tropical storm Able. Hurricane symbols indicate 24-hour positions. Intervening 6-hour positions are indicated by an "X". Plotted number groups indicate time and date (GMT/Date) of positions.

EARLY DEVELOPMENT AND MOVEMENT

Storm Able originated from a development on a wave in the easterlies. When discovered on August 25, organization of the storm circulation was incomplete. Development was slow and until August 29 the southern semi-circle of the storm remained open with observed winds of not over 25 knots. The first winds of hurricane force, observed by aerial reconnaissance, were reported in squalls located in the northern semi-circle of the storm on August 27. On August 30, 1952, storm Able slowed down in its forward movement. Intensification with the formation of a definite eye took place and indications of recurvature were noted. The storm at this point was located about 130 miles east-southeast of Jacksonville, Fla. (fig. 2). Following recurvature the hurricane moved toward the north and crossed the South Carolina coast at Beaufort.

An interesting feature of storm Able, after recurvature took place, was the report of an apparent double eye structure. In a post-flight summary August 30, Navy reconnaissance reported a principal eye of 38 miles diameter and a secondary eye located just a few miles to

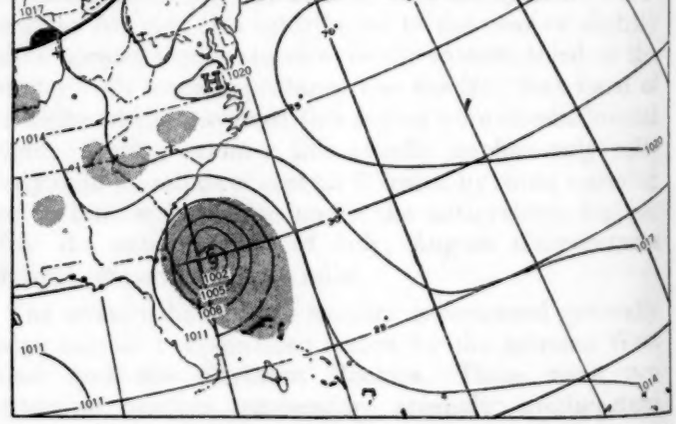


FIGURE 2.—Surface weather map for 1230 GMT, August 30, 1952. Shading indicates areas of active precipitation.

the southwest of the principal eye. Again, on August 31 a post-flight summary verified the existence of a secondary eye in the same relative position. This same summary reported maximum winds of 110 knots, the highest winds encountered during the existence of the storm.

RECURVATURE AND STEERING

At the time recurvature was indicated, the determination of the exact path that the storm might take posed a difficult problem. However, there were certain significant features in the synoptic situation which indicated that the storm might move with a more northerly component.

On August 30 a wave developed on a cold front just to the south of Newfoundland. Rapid cyclogenesis, associated with a strong surge of cold air aloft in the area, caused this wave to develop into a storm of major proportions within 24 hours (figs. 2 and 3). Although the entire wave structure is not shown in the figures, some idea of the intensity of the development is portrayed. With the intensification of this surface wave, a deepening and an apparent retrogression of the associated stationary trough aloft took place (figs. 4, 5, and 6). The upper air ridge located to the west of the trough, as shown in this sequence of 400-mb. charts, was displaced to the south and west, perhaps limiting the sharpness of the recurvature of the storm.

Another feature that may have influenced the path taken by storm Able, was a trough located over the Mississippi River region (see Boyce et al. [2]). In view of the weak circulation aloft in the immediate vicinity of storm Able, however, evidence that the steering was influenced by this trough to the west is not conclusive. Still another feature favorable (see [2]) for recurvature of the storm was the southward trend of the maximum westerlies at 600 mb. at this time as shown in figure 7.

Warm tongue steering of tropical cyclones has been suggested by Simpson [3]. The difference in height between the 700- and 500-mb. pressure surfaces appears to give the best results. Simpson says:

> "The analysis of temperature fields for this intermediate layer reveals that a tongue of warmer, lighter air is associated with the moving tropical cyclone and extends from 800 to 1200 miles in advance of the storm. The major axis of this tongue of warm air is parallel to the instantaneous direction of storm movement. Experience in testing this effect has shown that a good lag correlation exists between the present orientation of the warm tongue and the future path of the storm. In 139 synoptic cases analyzed the 24-hour movement given by this simple steering principle differed seriously from the observed movement in only four instances, and on many occasions important changes in direction were indicated as much as 48-hr. in advance."

To examine the warm tongue steering effect, thickness charts for the layer between 500 and 700 mb. for 0300 GMT on August 30, 31, and September 1, 1952, were constructed (figs. 8, 9, and 10). The path that the storm might follow is not definitely indicated by the first of these figures. The following two figures, however, clearly show that the major axis of the warm tongue was almost identical to the track taken by the storm (fig. 1).

Forecasters commonly make use of the high level wind flow to determine the future direction of motion of hurricanes. After reading a draft of this article, Mr. Grady Norton, Meteorologist in Charge of the Miami Weather Bureau Office, wrote, ". . . we thought this was a very good example of high-level wind 'steering'." Pointing out that wind steering is never used for longer than 30-hour periods, he further stated that their warnings for this hurricane were based on the winds at the 30,000- and 35,000-foot levels, where the hurricane circulation was absent. Figure 11 is a reproduction of a copy, furnished by Mr. Norton, of the 35,000-foot winds aloft working chart made at the Miami office at the time. Comparison of figures 1 and 11 reveals that the streamline through the hurricane is close to the path of the storm up to the time it passed inland about 24 hours later.

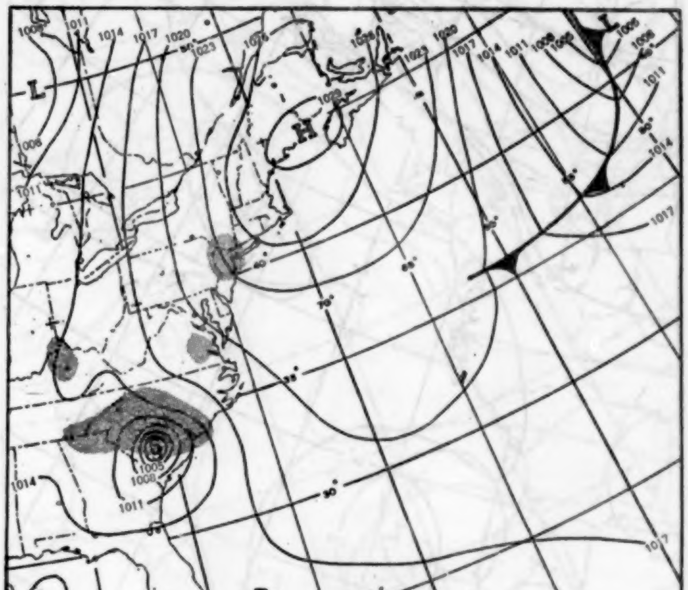


Figure 3.—Surface weather map for 1230 GMT, August 31, 1952.

THE STORM INLAND

On August 31, 1952 Navy reconnaissance reported the northwest edge of the storm's eye over the coastline at 0255 GMT. By 0345 GMT the eye of the storm had moved inland. A vertical cross section (fig. 12) was constructed using 0300 GMT, August 31, 1952 radiosonde data (very close to the time storm Able crossed the coastline). The stations used were Jacksonville, Fla., Charleston, S. C., and Greensboro, N. C. Unfortunately the Charleston sounding ended just short of the 500-mb. level so details of the structure above that level are missing. The eye of the storm passed close to, but not over, Charleston, so the central structure is not known. Arakawa [4] shows in detail the vertical structure of a mature typhoon. The data available to him consisted of a large number of radiosonde and wind observations from a network of closely spaced stations with one radiosonde flight near the core of the typhoon. According to Arakawa there is descending motion within the core and ascending motion just outside the core of the storm. The vertical cross section constructed for storm Able, although it does not show the central structure, shows cooling in the vicinity of Charleston which may be attributed to the vertical motion near the eye of the storm and to the heavy precipitation in advance of the eye. The lapse rate and the dew point curves for Charleston at 0300 GMT on the 31st are very similar to the findings of Jordan [5] on the low level structure of the typhoon.

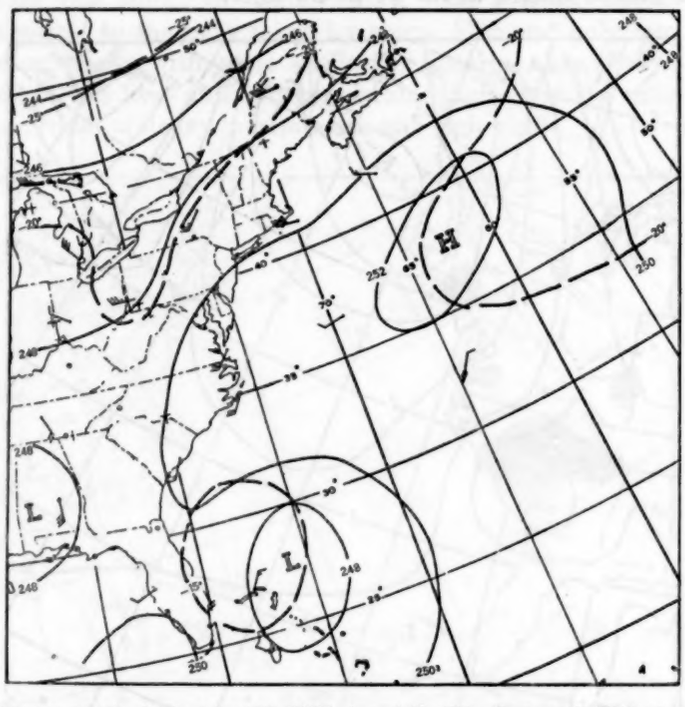


FIGURE 4.—400-mb. chart for 1500 GMT, August 29, 1952. Contours (solid lines) at 200-foot intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are at intervals of 5° C. Barbs on wind shafts are for wind speeds in knots; full barb for every 10 knots and half barb for 5 knots.

The following is quoted from the preliminary report on storm Able by Mr. Grady Norton:

"Beaufort was in the western edge of the calm center with unofficial pressure of 29.09 inches (985 mb.) and strongest wind 80 to 90 m. p. h.

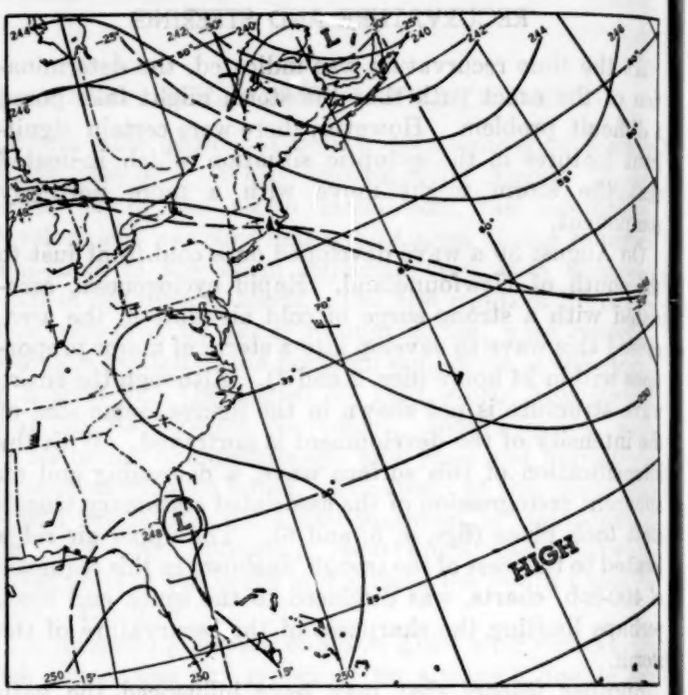


FIGURE 5.—400-mb. chart for 1500 GMT, August 30, 1952.

FIGURE 6.—400-mb. chart for 1500 GMT, August 31, 1952.

from WSW after the lull, which lasted about 10 minutes from 10:20 to 10:30 p. m. The strongest wind would be expected on the right or eastern side of the eye, but this was over the marsh and swamplands between Beaufort and Charleston where no measurements were obtainable. At Charleston, about 50 miles east of the center, the wind reached 63 m. p. h., while at Savannah, about 30 miles west, the highest gusts were only 35 m. p. h.

"Damage was estimated at about $2,200,000 in South Carolina, divided roughly $500,000 to property, $200,000 to communications, and $1,500,000 to crops. The crop damage was most-

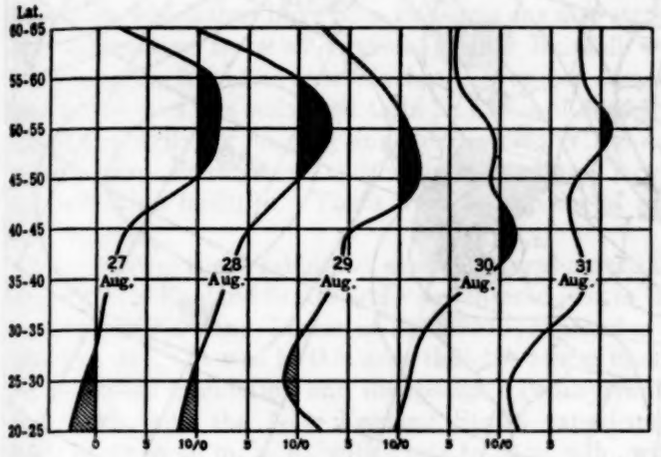


FIGURE 7.—Zonal wind profile curves at the 600-mb. level for the zone between 20° W. and 135° W. longitude. Curves derived by computing westerly component of the average wind for intervals of 5° of latitude. Magnitude of the westerlies is in degrees of latitude per day.

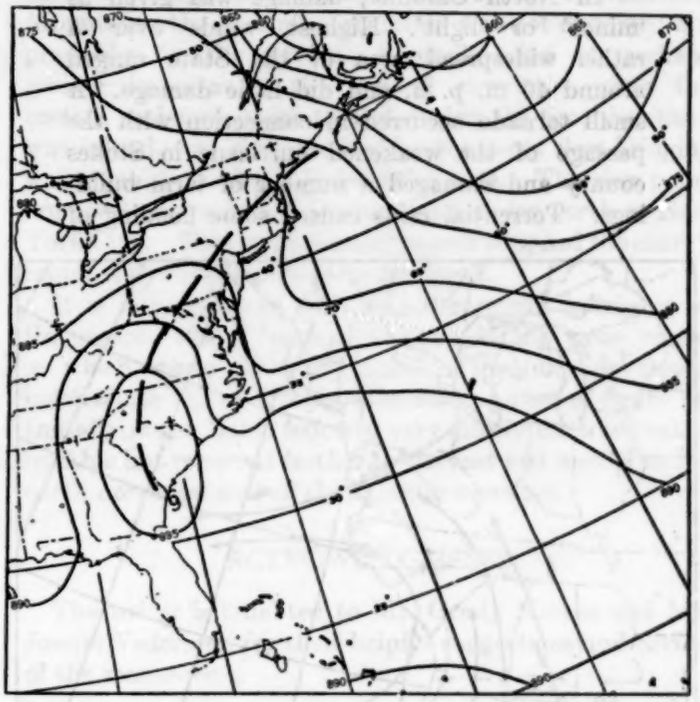


FIGURE 9.—Height difference chart between 700 and 500 mb. for 0300 GMT, August 31, 1952.

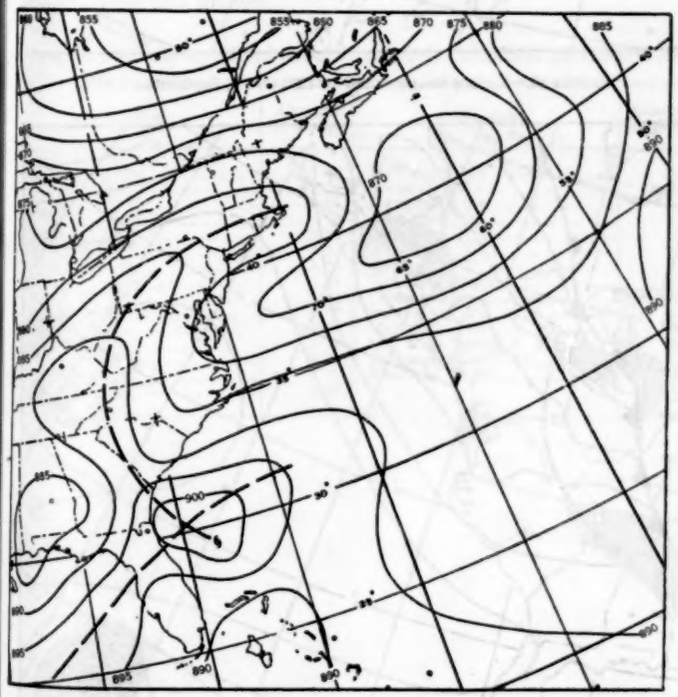


FIGURE 8.—Height difference chart between 700 and 500 mb. for 0300 GMT, August 30, 1952. Isopleths of mean virtual temperature (solid lines) are labeled in terms of height difference for 50-foot intervals. Axis of warm tongue indicated by heavy dashed line.

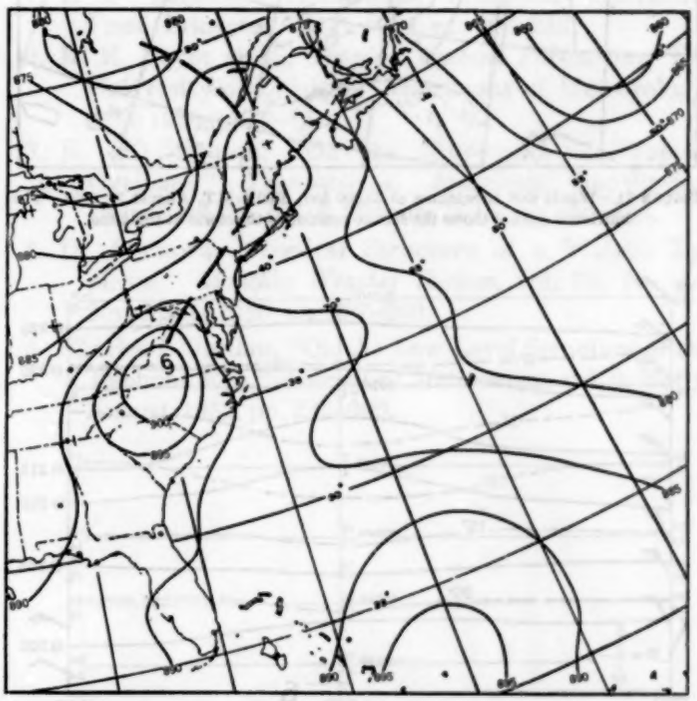


FIGURE 10.—Height difference chart between 700 and 500 mb. 0300 GMT, September 1, 1952.

ly to open cotton blown on the ground and damaged. Most of it was salvaged but beating by wind and rain in dirt lowered grade and price.

"In North Carolina, damage was given as 'minor' or 'light'. Highest winds over a rather widespread area of the State ranged around 40 m. p. h. and did little damage. A small tornado occurred in connection with the passage of the weakened hurricane in Stokes county and damaged a number of farm buildings. Torrential rains caused some flooding of lowlands, and a number of highways were flooded for a short time, and a few small bridges and embankments were washed out. The total actual damage probably did not exceed $50,000.

"Two persons lost their lives in the hurricane in South Carolina, one man was killed when he tried to remove a live wire that had fallen on his automobile, while another was killed when his car was

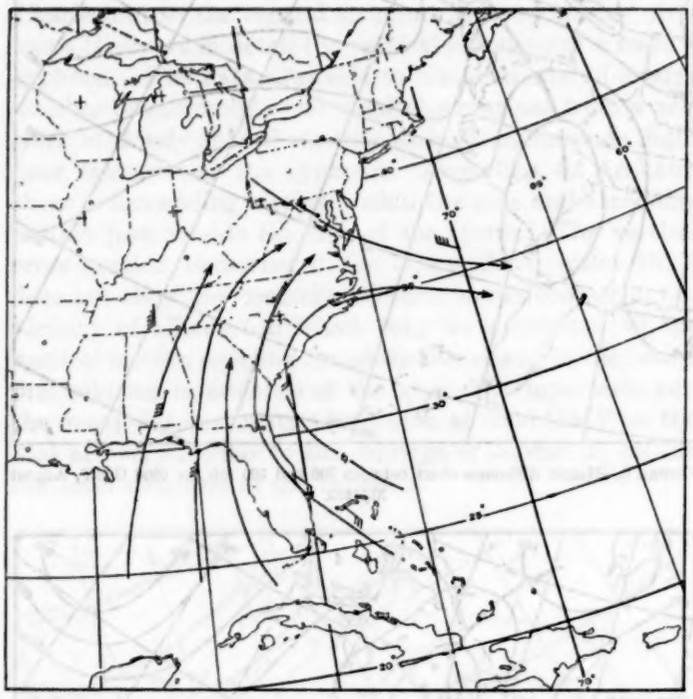


FIGURE 11.—Winds and streamlines at 35,000 feet, 0300 GMT, August 30, 1952. The hurricane symbol shows the surface position of the storm at this time.

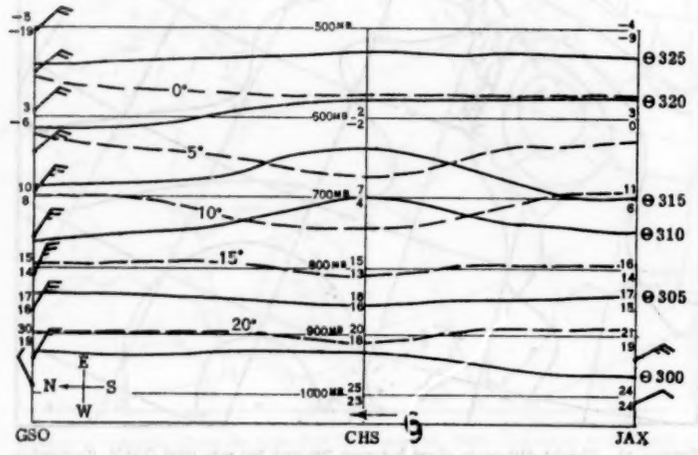


FIGURE 12.—Vertical cross section through hurricane Able for 0300 GMT, August 31, 1952. Temperature (dashed lines) is in ° C., potential temperature (solid lines) in ° A. Temperature and temperature of dew point in ° C. is shown at significant levels. Barbs on wind shafts are for wind speeds in knots; full barb for every 10 knots and half barb for 5 knots.

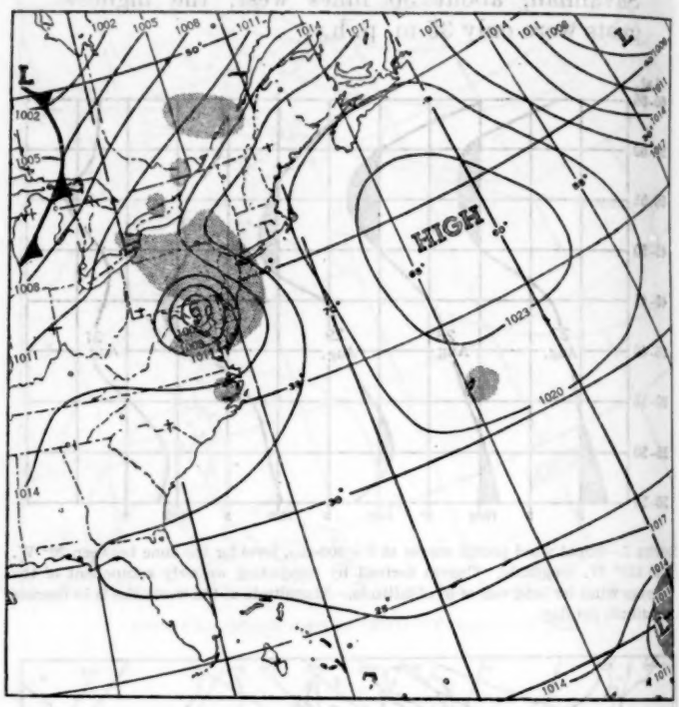


FIGURE 13.—Surface weather map for 1230 GMT, September 1, 1952.

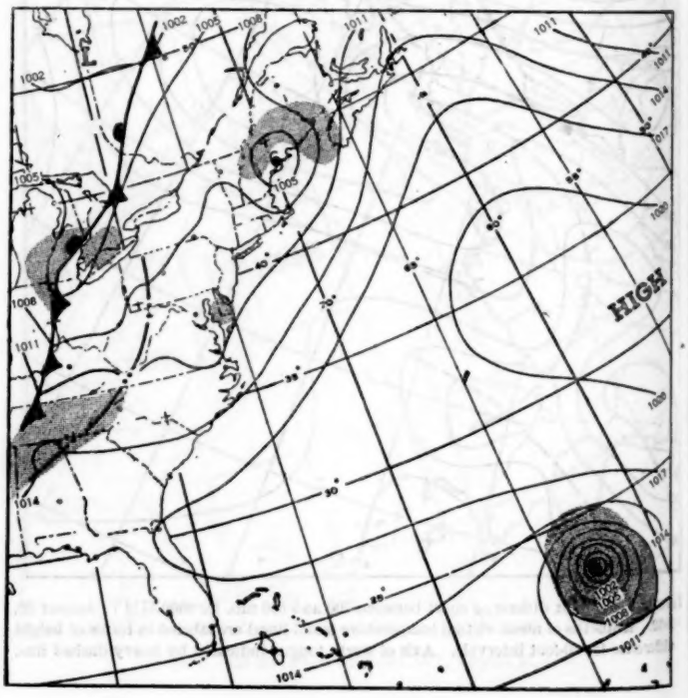


FIGURE 14.—Surface weather map for 1230 GMT, September 2, 1952.

wrecked in the blinding rain when it struck a tree that had fallen on the highway."

The storm center as shown in figure 3 was located just to the northeast of Columbia, S. C., at 1230 GMT, August 31, 1952; 24 hours later the center had moved to Frederick, Md., northwest of Washington, D. C. (fig. 13). The storm in the Washington, D. C., area was attended by winds 35 to 40 m. p. h., with occasional gusts up to 50 m. p. h. The peak gust reported at Washington National Airport was 60 m. p. h. A small tornado did considerable damage to dwellings at Franconia, Va., in Fairfax County. A tornado, which may have been the same one also struck with destructive force at Potomac, Md. Rainfall was heavy, ranging from 2 to over 3 inches. Property damage done in the area was estimated to be in excess of $500,000, caused primarily by flooding and the destructive force of the tornado. Falling trees and branches disrupted power and telephone facilities. There were no reports of personal injuries.

After leaving the Washington area the storm moved up into the New England States and was centered just to the northwest of Portland, Maine, at 1230 GMT, September 2, 1952 (fig. 14). It was in this area that the storm finally lost its closed circulation and dissipated. Pennsylvania, New York, and the New England States experienced winds of 30 to 40 m. p. h., with gusts to 50 m. p. h., with passage of the storm. Rainfall was moderate to heavy, resulting in some flooding in localized sections. Some unofficial rainfall amounts are shown in table 1 for stations affected by the storm.

TABLE 1.—*Some unofficial rainfall amounts associated with storm Able*

Station	Amount in inches	Station	Amount in inches
Jacksonville, Fla	1.69	Baltimore, Md	4.27
Savannah, Ga	1.16	Frederick, Md	3.70
Charleston, S. C	2.01	Harrisburg, Pa	3.60
Myrtle Beach, S. C	4.75	Allentown, Pa	5.08
Florence, S. C	3.83	Teterboro, N. J	2.07
Columbia, S. C	1.69	New York, N. Y	1.20
Charlotte, N. C	3.76	Albany, N. Y	2.47
Fort Bragg, N. C	6.33	Pittsfield, Mass	2.77
Raleigh, N. C	3.66	Chicoppee Falls, Mass	1.47
Greensboro, N. C	2.67	Summerset, Vt	3.27
Roanoke, Va	2.61	Montpelier, Vt	2.82
Lynchburg, Va	2.52	Mt. Washington, N. H	2.10
Gordonsville, Va	2.55	Portland, Maine	1.15
Martinsburg, W. Va	3.72	Rumford, Maine	2.37
Washington, D. C	3.47		

Storm Able, although never really developing into a large storm over the ocean maintained its circulation and identity as a tropical storm over a long land trajectory. Two important features can account for this. First, since the trajectory remained east of the Appalachian Mountains, the storm's circulation was not distorted appreciably by the terrain. Secondly, and of perhaps greater importance, the general circulation over the eastern seaboard, prior to and during the time the storm was inland, was characterized by southerly flow bringing warm moist tropical air into the area. The dew point temperatures ranged in the seventies as far north as New York City. This tropical maritime air supplied the energy required by the storm to maintain itself.

It is interesting to note that the second hurricane of the season, storm Baker, developed in the same region in which storm Able originated. This fully developed hurricane is shown inthe southeastern corner of figure 14. Initially, storm Baker followed very closely the track taken by Able but recurved farther to the east and moved to the north-northeast well off the Atlantic coastline.

ACKNOWLEDGMENTS

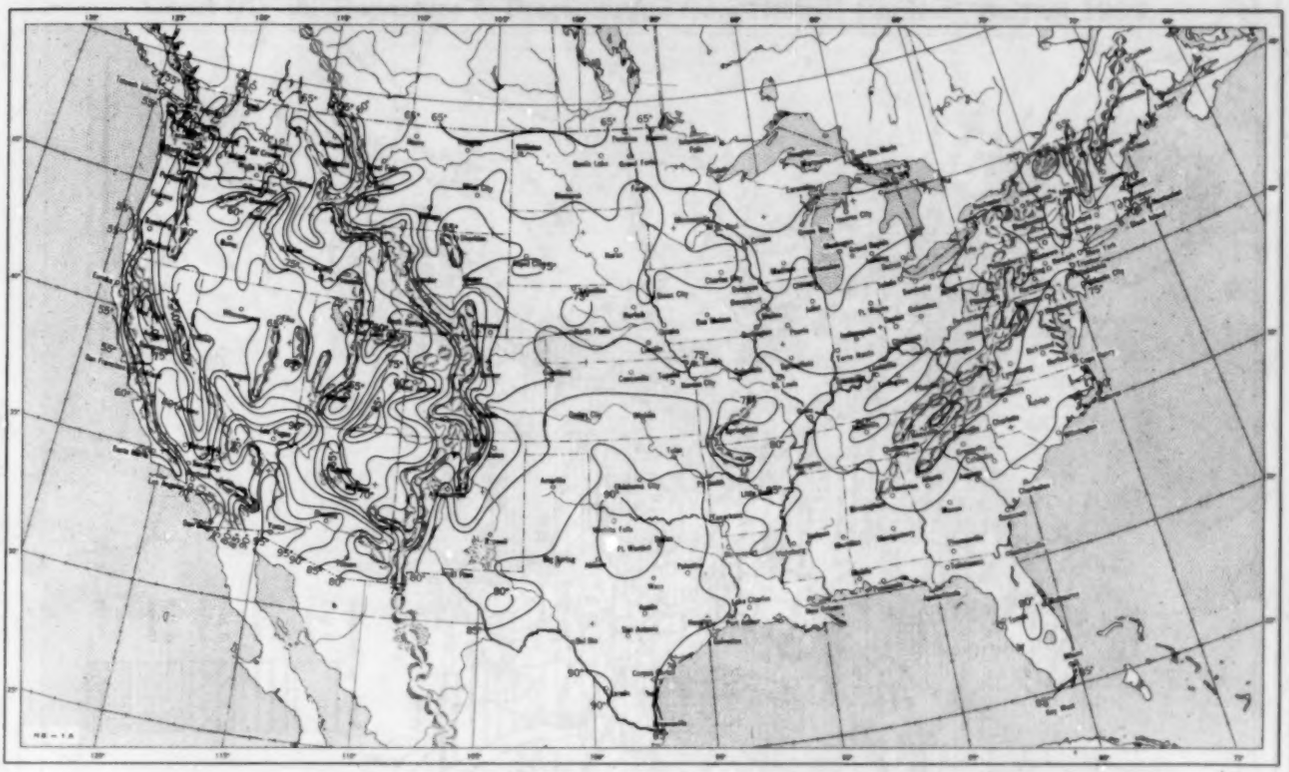
The writer is indebted to Mr. Grady Norton and Mr. Joseph Vederman for their helpful suggestions and review of the manuscript.

REFERENCES

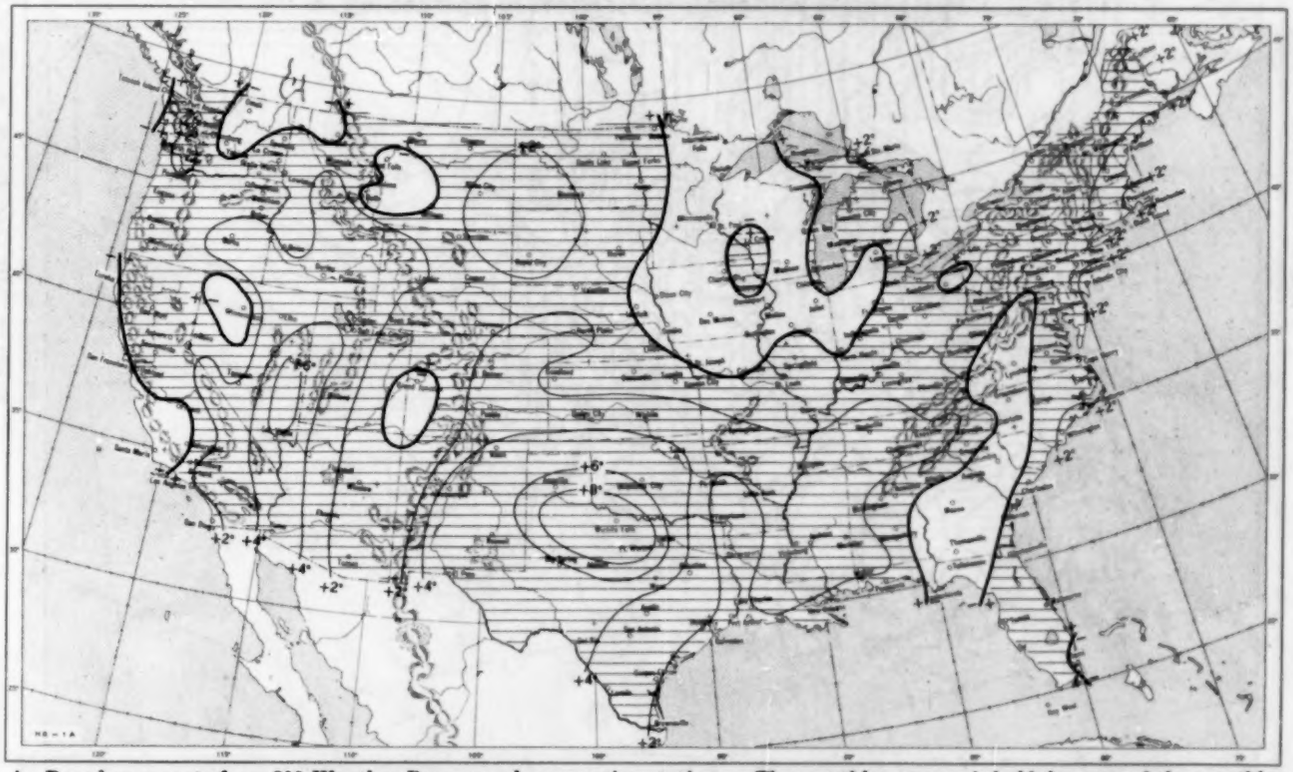
1. I. R. Tannehill, *Hurricanes*, Princeton University Press, Princeton, N. J., 1950, pp. 163–238.
2. R. E. Boyce et al., *Tropical Cyclone Forecasting*, The University of Chicago, Department of Meteorology, June 1950, pp. 9–11.
3. R. H. Simpson, "On the Movement of Tropical Cyclones," *Transactions*, American Geophysical Union, vol. 27, No. 5, October 1946, pp. 650–655.
4. H. Arakawa, "Vertical Structure of a Mature Typhoon," *Monthly Weather Review*, vol. 78, No. 11, November 1950, pp. 197–200.
5. Charles L. Jordan, "On the Low Level Structure of the Typhoon Eye," *Journal of Meteorology*, vol. 9, No. 4, August 1952, pp. 285–290.

U. S. GOVERNMENT PRINTING OFFICE: 1952

Chart I. A. Average Temperature (°F.) at Surface, August 1952.

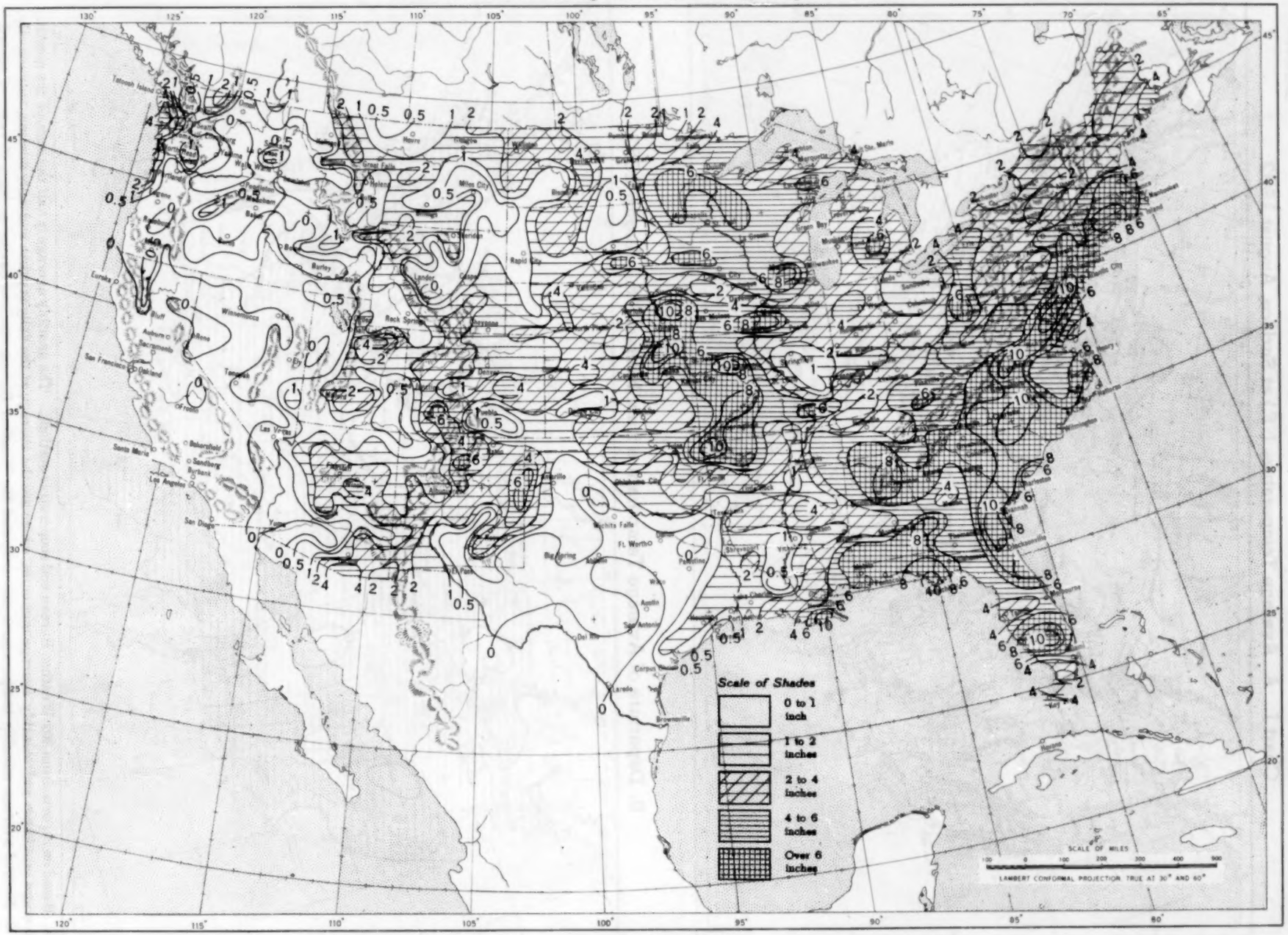


B. Departure of Average Temperature from Normal (°F.), August 1952.



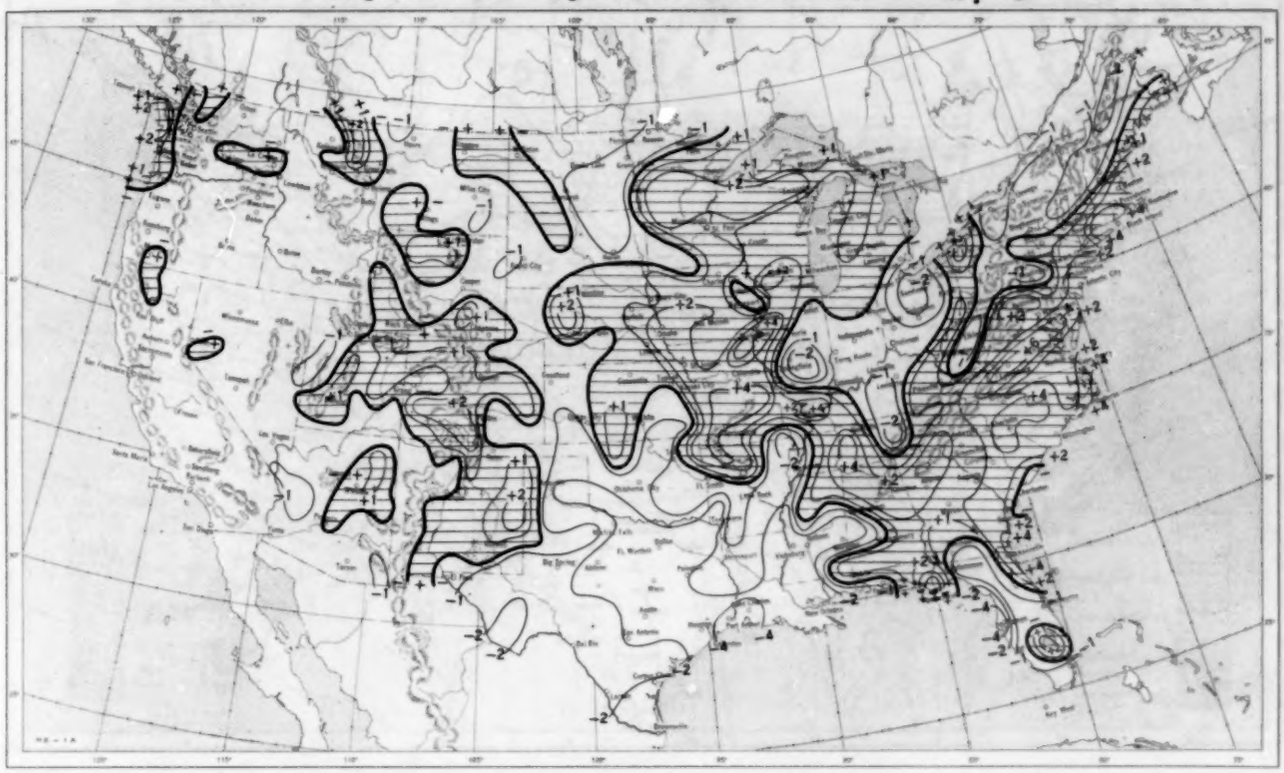
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), August 1952.

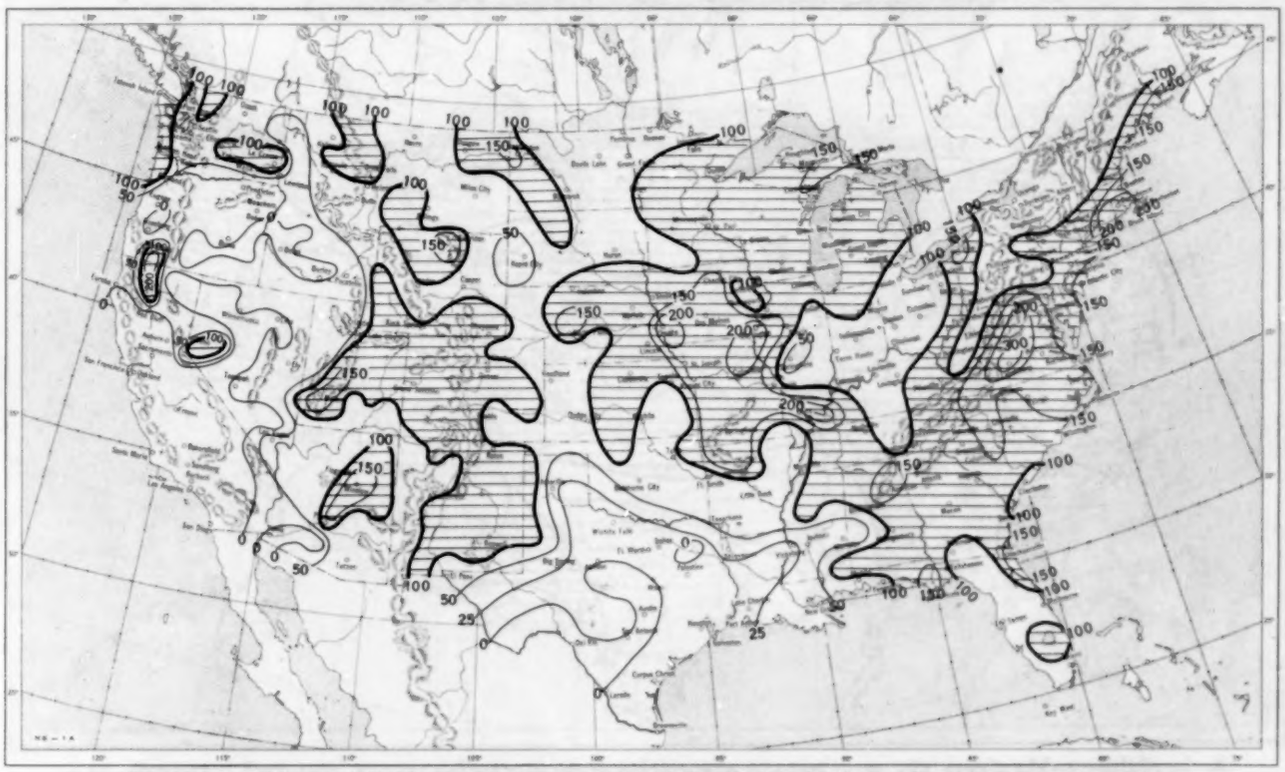

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), August 1952.

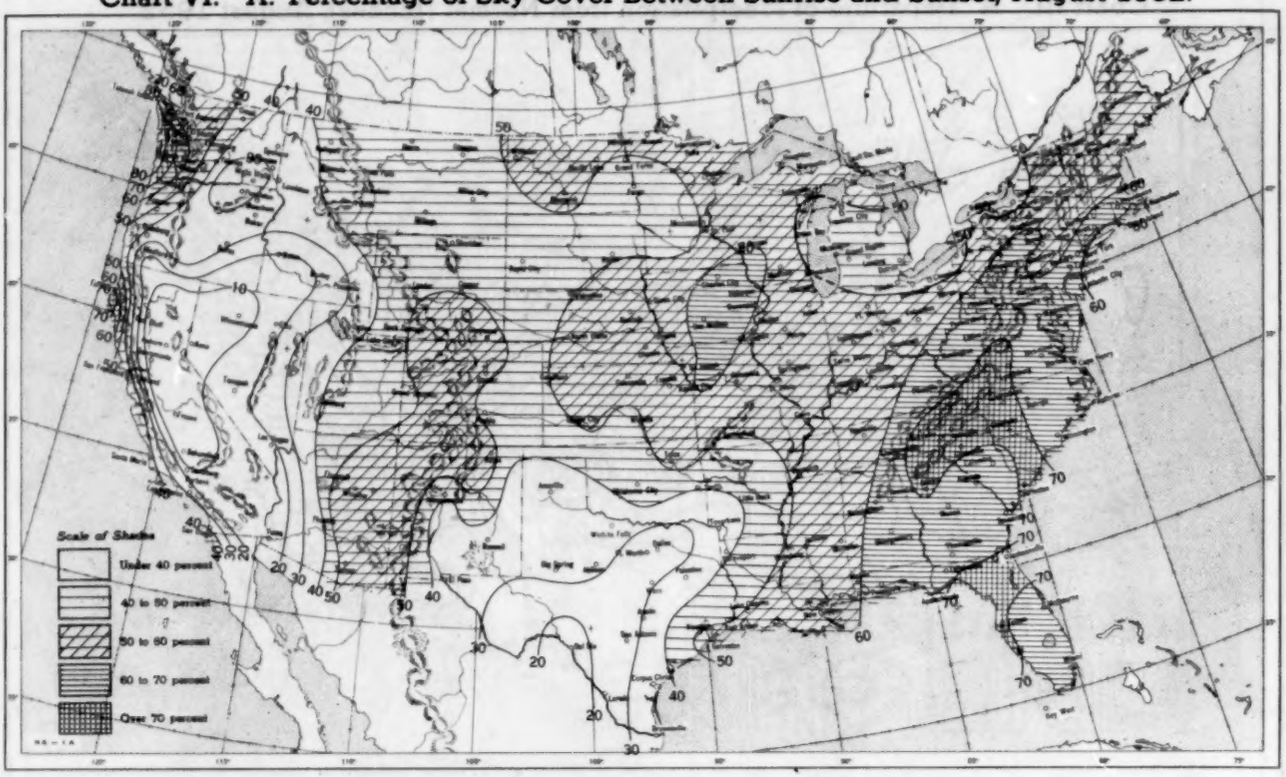


B. Percentage of Normal Precipitation, August 1952.

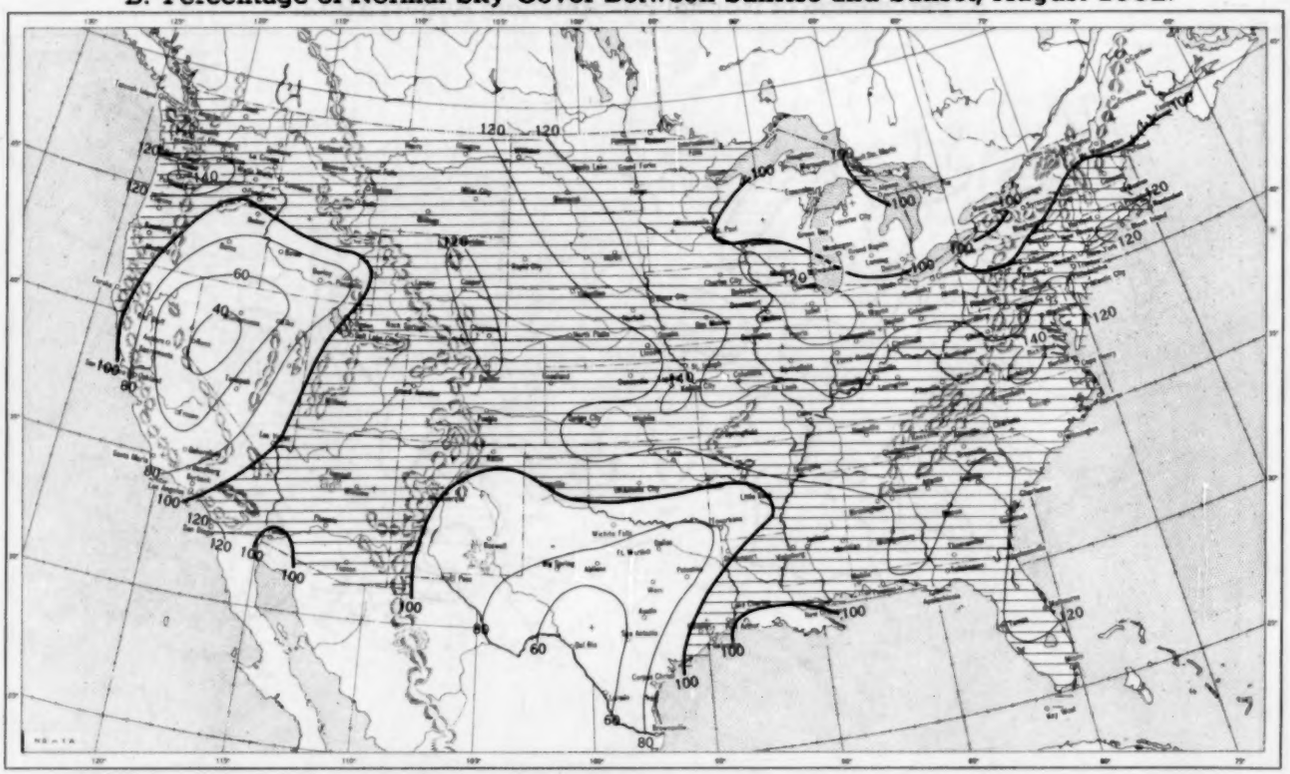


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, August 1952.

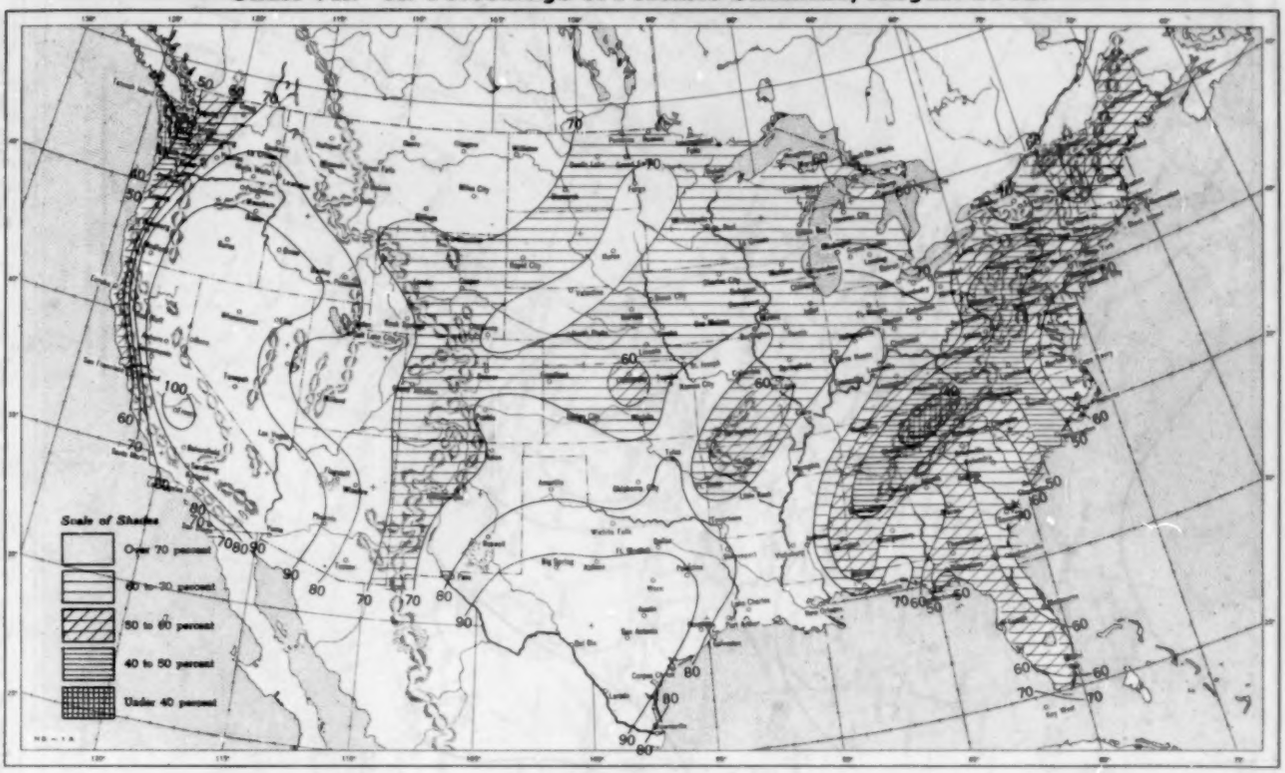


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, August 1952.

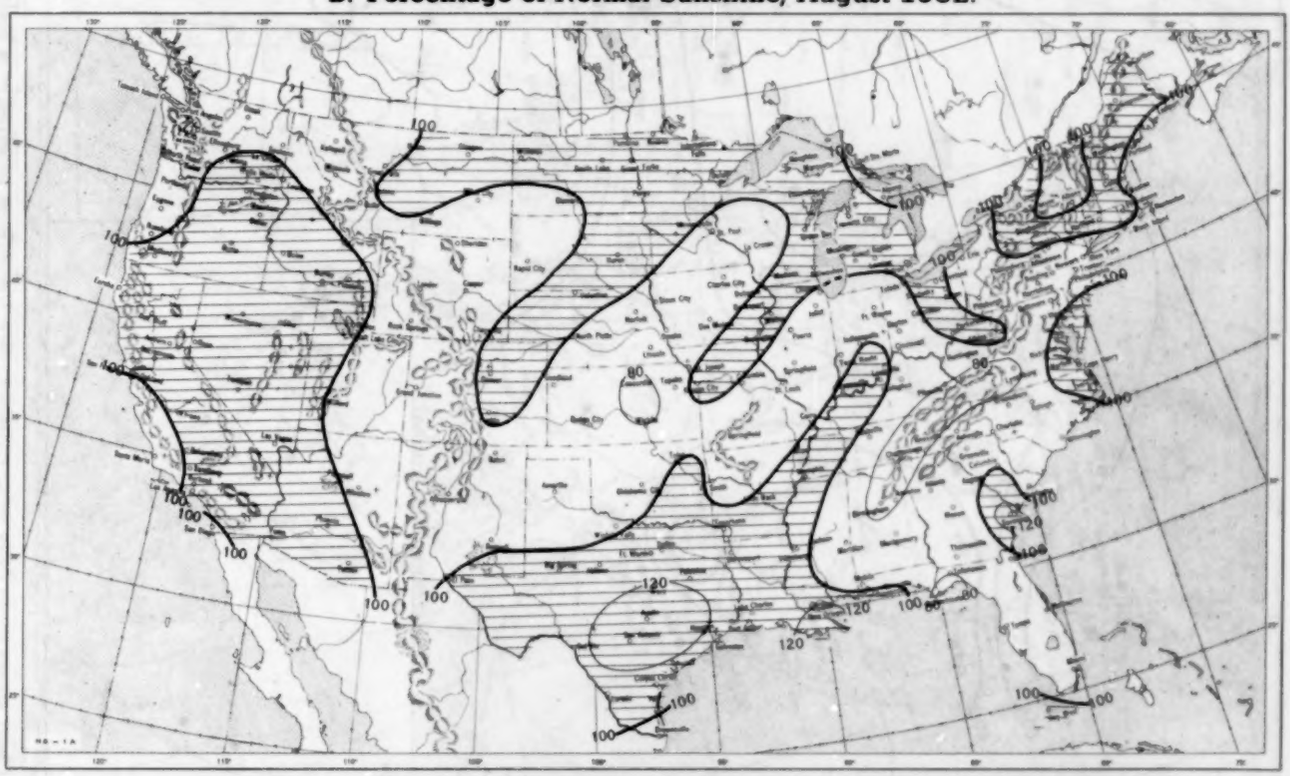


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, August 1952.



B. Percentage of Normal Sunshine, August 1952.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, August 1952. Inset: Percentage of Normal Average Daily Solar Radiation, August 1952.

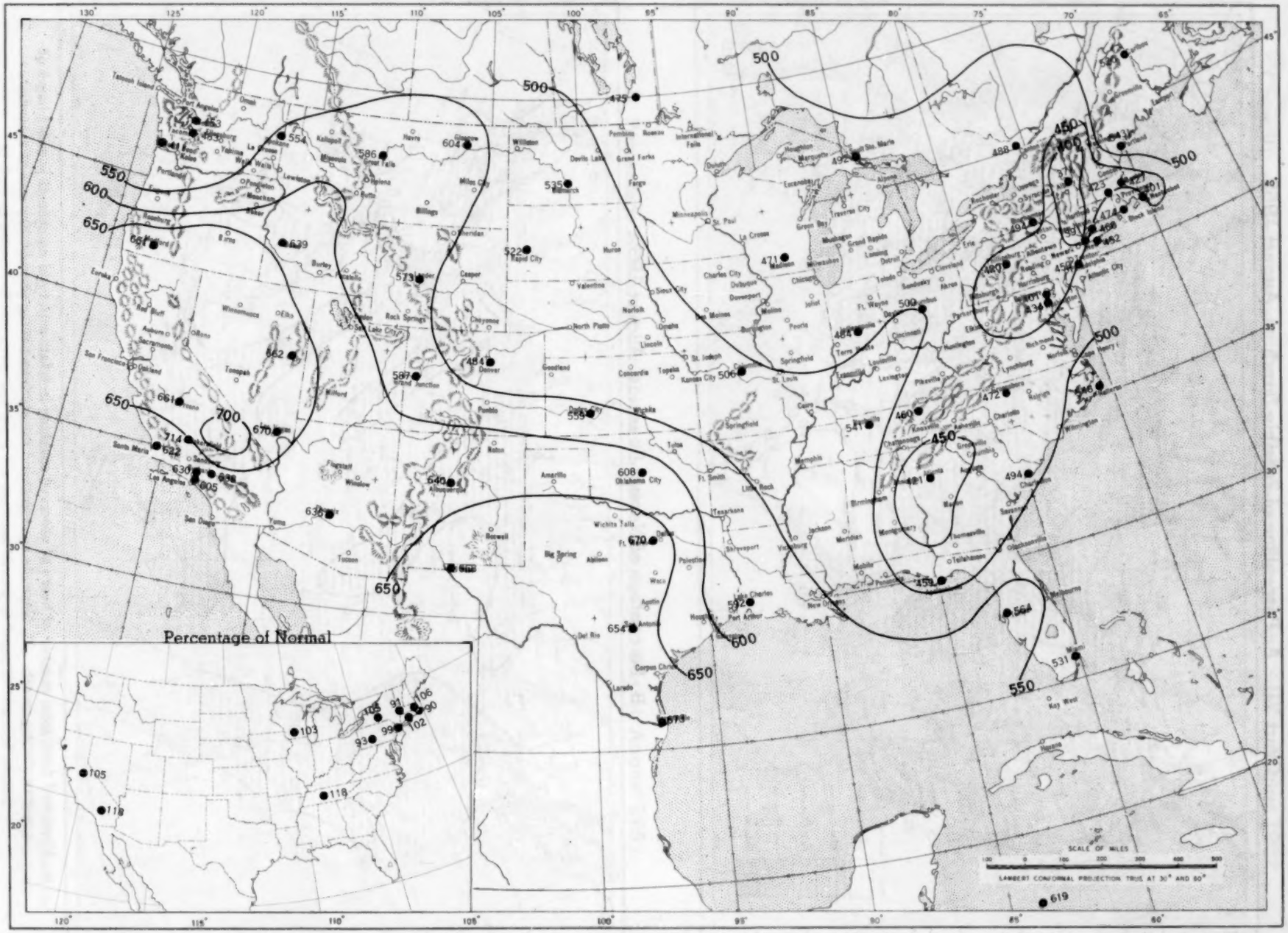
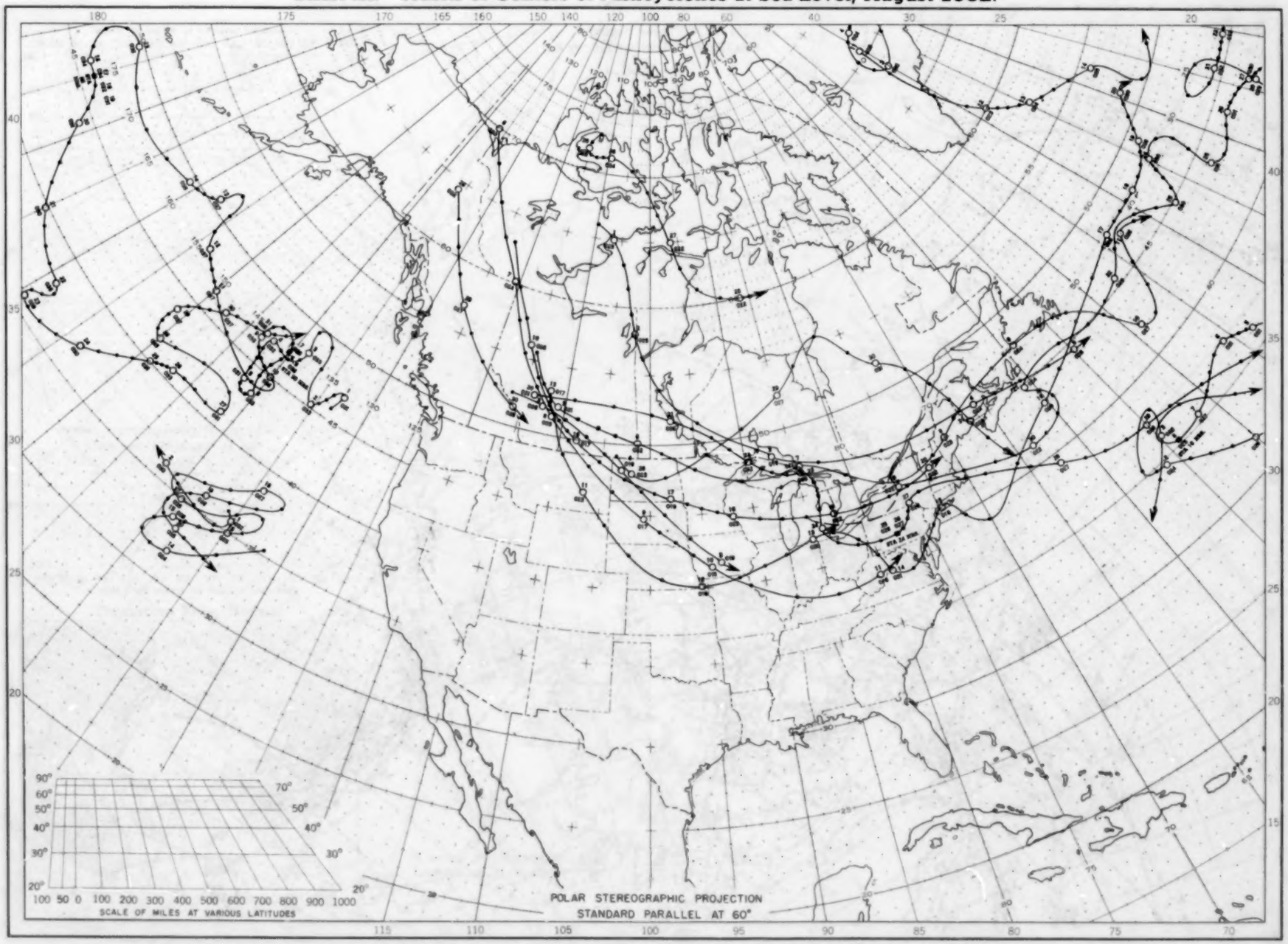


Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

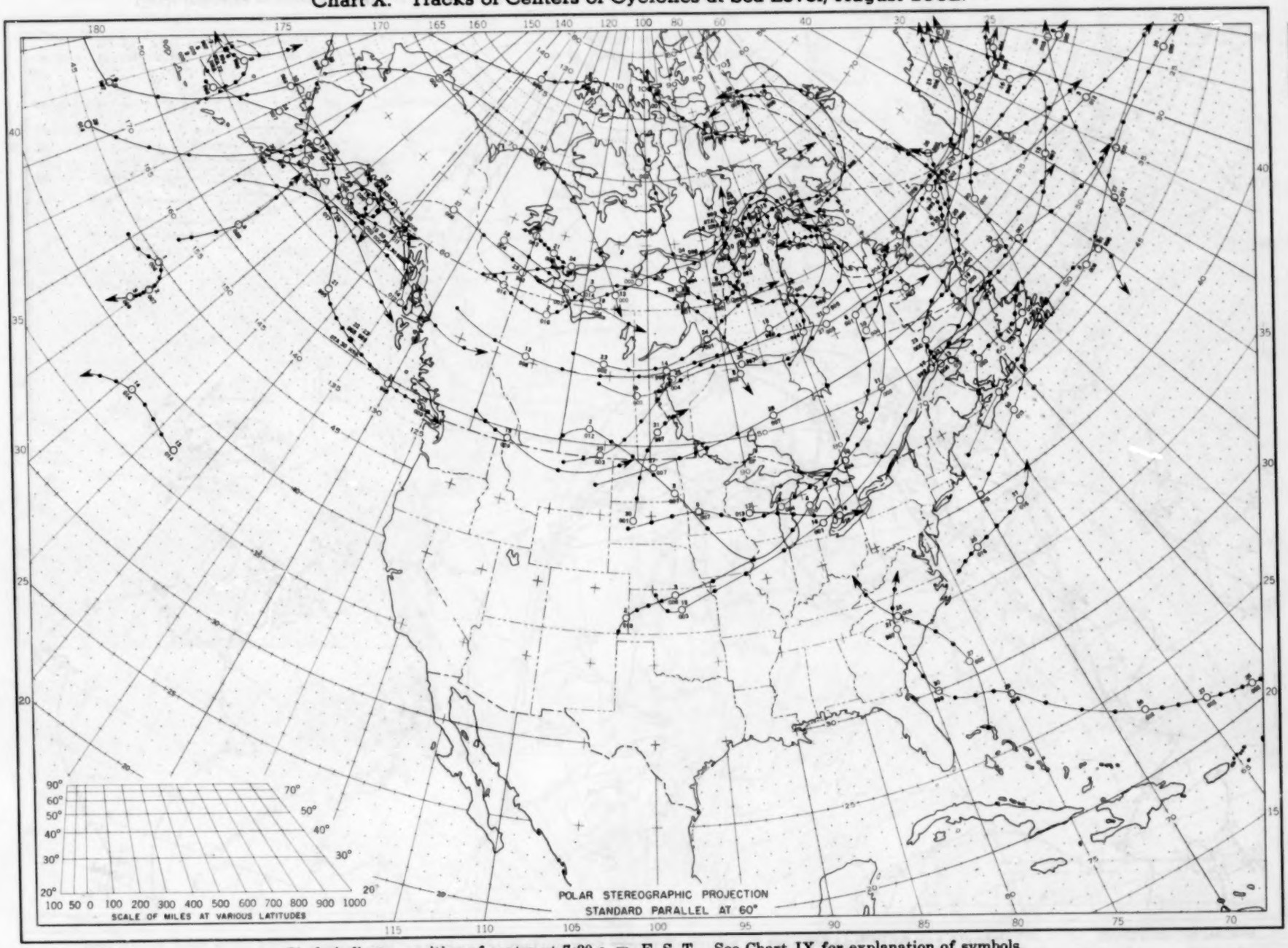
are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, August 1952.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000

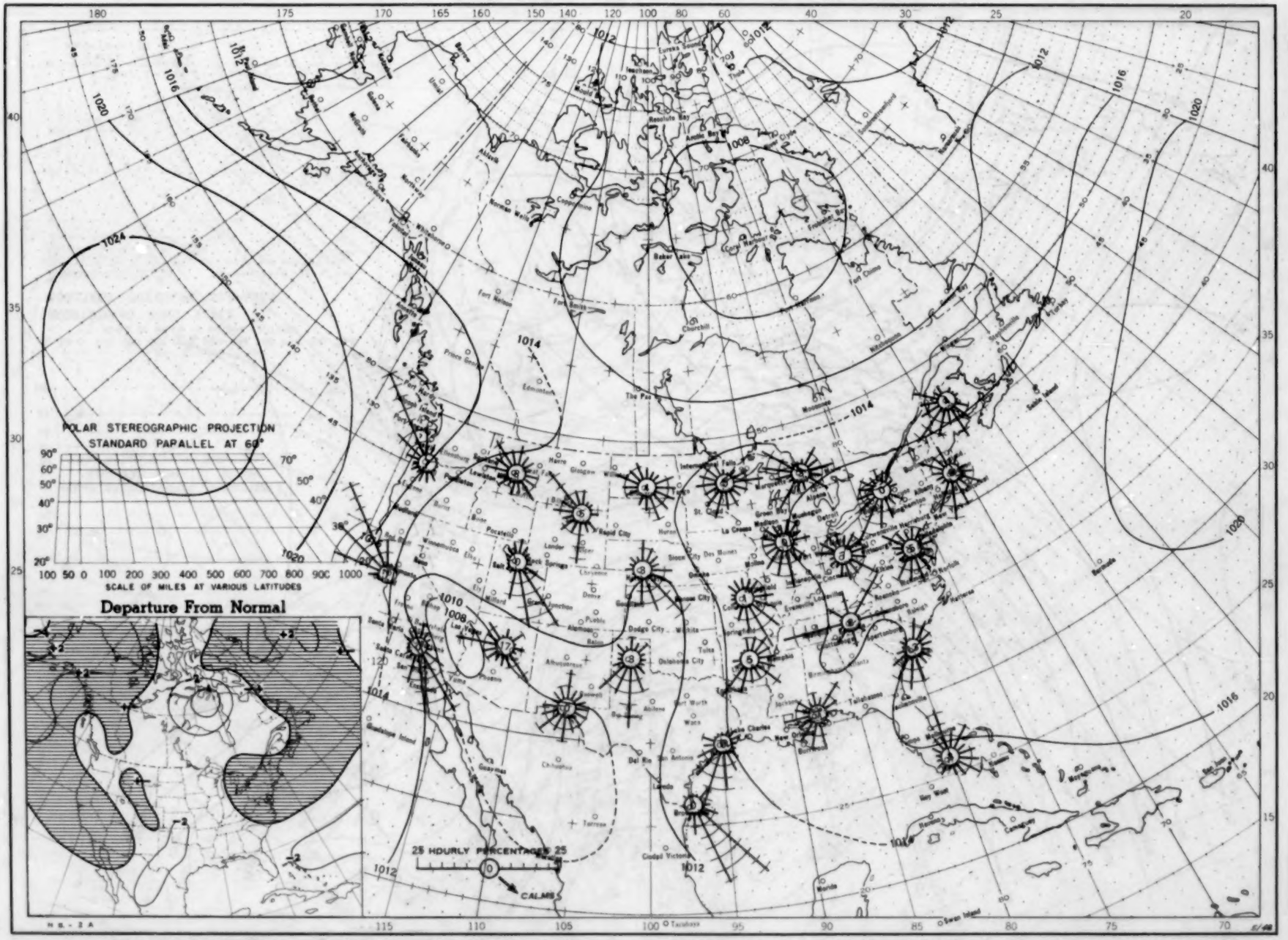
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, August 1952.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000

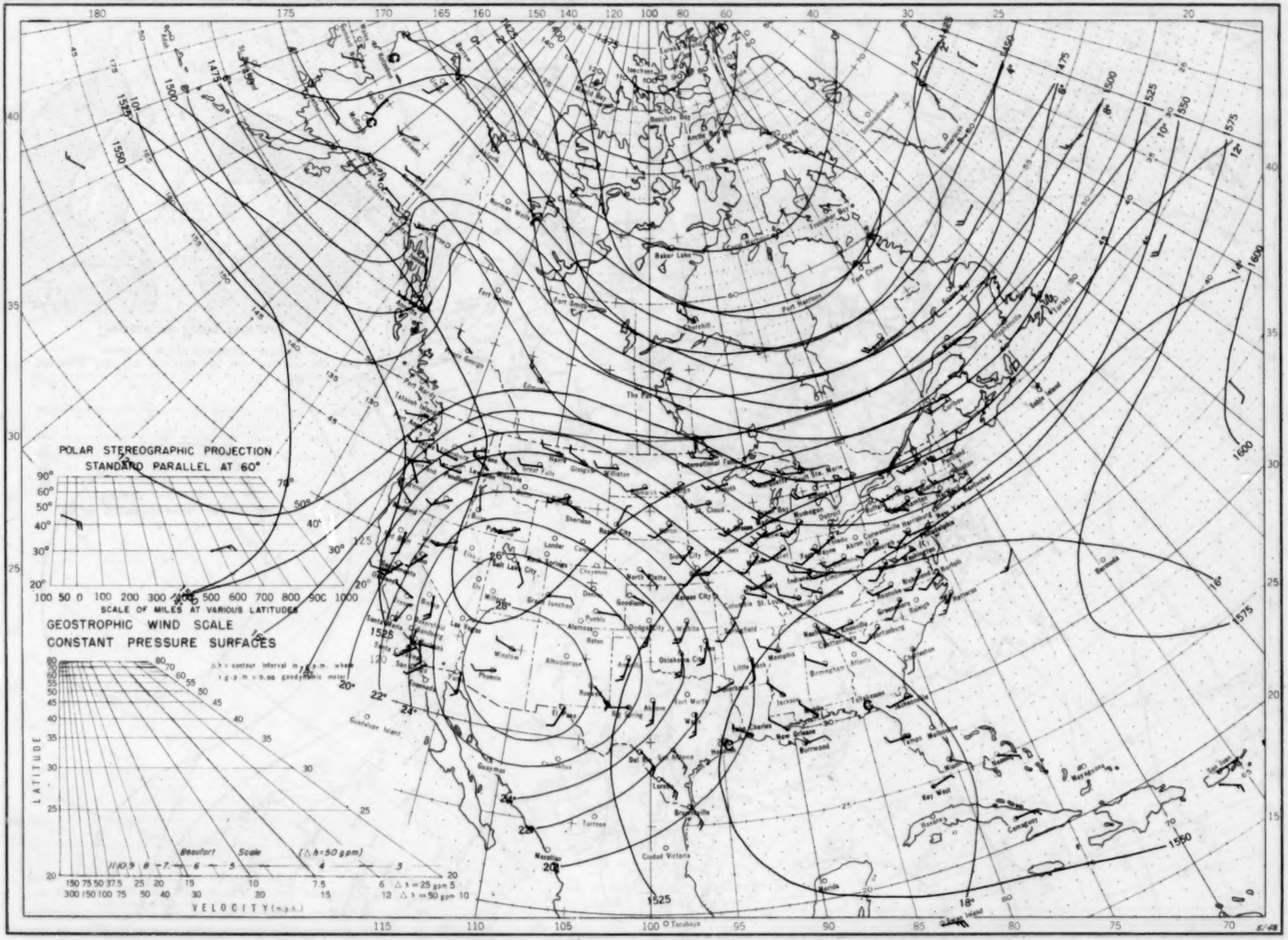
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, August 1952. Inset: Departure of Average Pressure (mb.) from Normal, August 1952.



Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

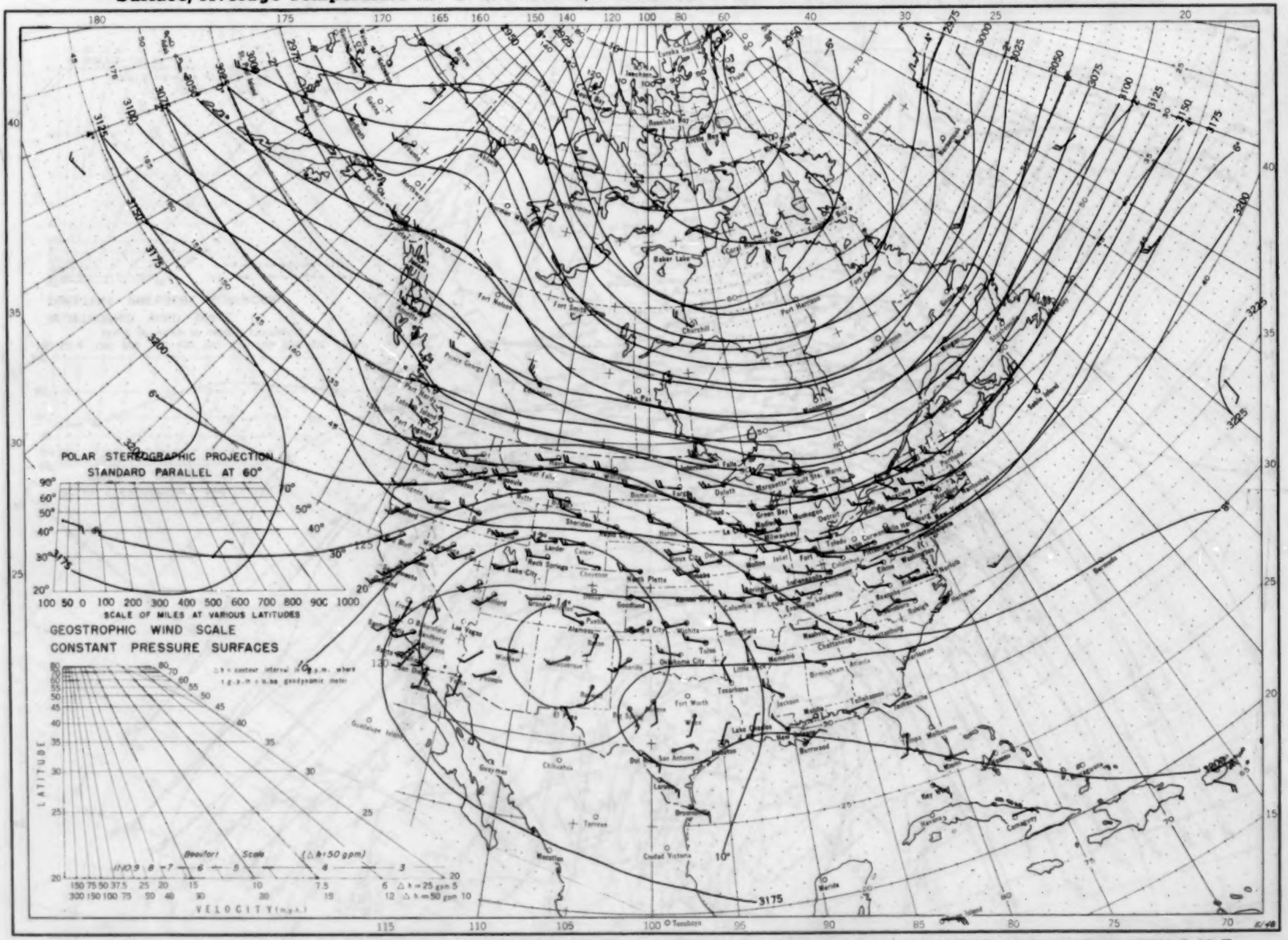
Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), August 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

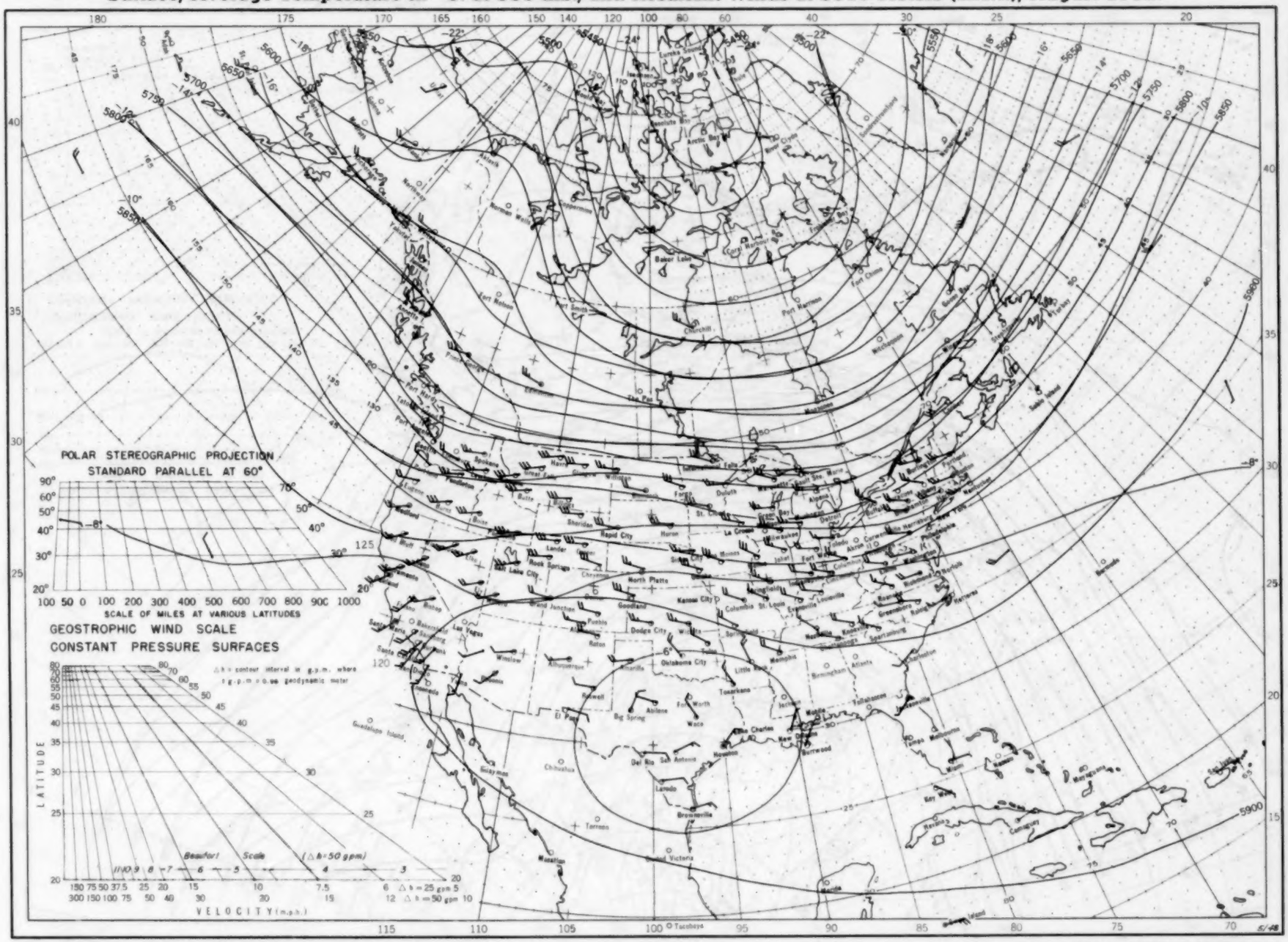
those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), August 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

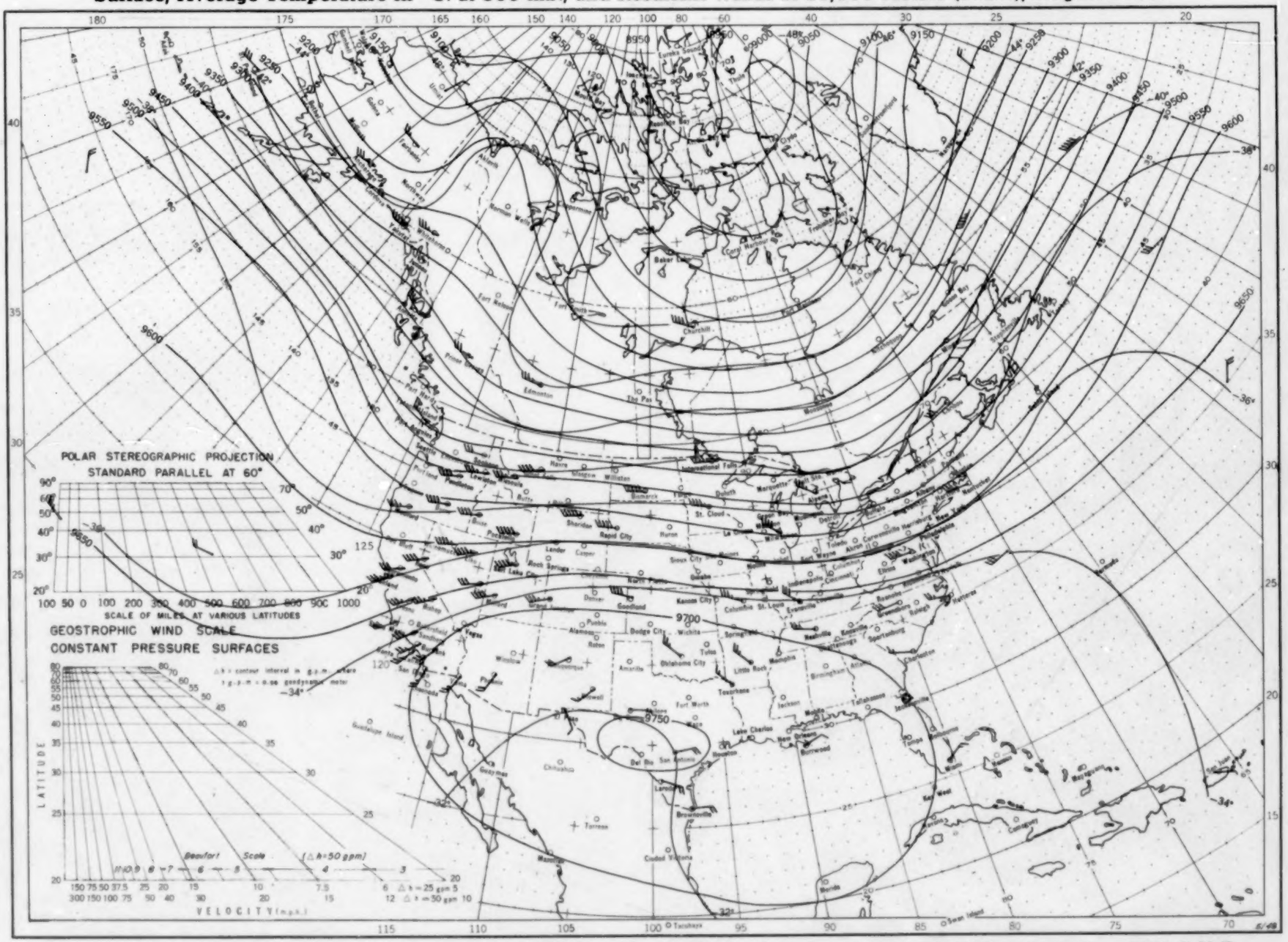
Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), August 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), August 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.